IOWA GEOLOGICAL SURVEY

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Annual Report, 1928

with

Accompanying Papers

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Geological Survey Organization

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THIRTY-SEVENTH ANNUAL REPORT OF THE STATE GEOLOGIST

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1928.

To Governor John Hammill and Members of the Geological Board:

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

The Pre-Illinoian Pleistocene Geology of Iowa by George F. Kay and Earl T. Apfel
The Maquoketa of Iowa by Harry S. Ladd
Mineral Production in Iowa in 1927 by James H. Lees.

The paper of nearly three hundred pages by Doctor Kay and Doctor Apfel represents the results of many years of field and laboratory study. It includes chapters on the Bedrock Surface of Iowa, the Topography and Drainage of Iowa, the History of Investigations and Classifications of the Pleistocene Geology of Iowa, the Nebraskan Glacial Stage, the Aftonian Interglacial Stage, the Kansan Glacial Stage, and the Yarmouth Interglacial Stage. As stated in the Preface, "It is the purpose of this paper to present the results of extensive field and laboratory studies made with special reference to the pre-Illinoian glacial and interglacial deposits. Some conclusions have been reached which differ from those of previous workers, and some new criteria have been found which aid in the interpretation of the complex history of the early part of the glacial period. The paper has been written with the hope that it will be of interest not only to students of Pleistocene geology but to the general reader as well." Elsewhere in the paper is the following statement: "It is now conceded by students of the Pleistocene that Iowa is an area where the records of the glacial and interglacial stages of the Glacial Period have been best preserved and where the deposits, glacial and interglacial, have been best studied in such detail as to permit of their satisfactory interpretation and classification.'' The detailed information given in this report about the various kinds of deposits which constitute the mantle materials of Iowa will furnish a basis for a better understanding of the characteristics, the origins, and the histories of the soils of the different parts of our great agricultural state.

Doctor Ladd's paper is Part I of a report on the stratigraphy and paleontology of the Maquoketa shale of the Ordovician system of northeastern Iowa. After a careful historical account of former work done on this formation, Doctor Ladd shows that the Maquoketa has two distinct lithological facies referred to as the Northwest Area and the Southeast Area. The latter consists chiefly of shale, the former of limestones and shales. The Maquoketa, long held to be Upper Ordovician in age, is still retained in that position. The author, however, feels it should be placed in the Silurian, final disposition depending on the age of the subjacent Dubuque dolomite, whose stratigraphy and paleontology are not yet satisfactorily determined. The author points out that the Richmond of Michigan is quite similar to the Maquoketa of Iowa and a possible correlation also with the Richmond of Ohio is considered. A depauperate zone at the base, a graptolite zone just above the base, and the Cornulites zone at the top are quite constant over both areas. The Depauperate fauna is thought to have invaded the region from the south as it is typically developed in the Cason shale of Arkansas. Certain fossils in the Northwest Area are boreal in aspect. Among these are *Streptelasma haysii* and a new *Lindströmia*. Hence a northern invasion in later Maquoketa time is suspected. Many of the brachiopods of the Maquoketa are Richmondian in aspect but the author believes that close study will serve readily to distinguish them from those of the Ohio valley. A number of such closely related species are here carefully compared with typical Richmond shells and their differences are pointed out. A complete report on the fauna, extending to more than two hundred species, will compose Part II, to appear later. In the forthcoming study Doctor Foerste will discuss the cephalopods and Doctor Shideler the bryozoa.

The paper by Doctor Lees on Mineral Production in Iowa in 1927 refers to the anomaly of an increase in value in 1927 in most branches of the industry but a decrease in total value in comparison with the figures for 1926. This was due to the strike among the union coal miners, which brought production of coal down from 4,625,487 tons in 1926, valued at $14,214,000, to 2,949,622 tons in 1927, with a value of only $9,304,000. On the other hand, shipments of cement made in the state were 18 per cent greater than in the previous year. One new plant was added to the list, that of the Dewey Portland Cement Company, at Davenport. This state now has an annual capacity of 7,935,000 barrels of finished cement.

The manufacture of clay brick and sewer pipe was somewhat less in 1927 than in 1926, but the production of hollow ware was somewhat greater and the output of drain tile was more than doubled. Total values for the industry were over half a million dollars greater in 1927 than in the preceding year.

The importance of the gypsum industry to Iowa increases almost every year. In 1927, 723,942 tons of gypsum and its products were marketed for $6,713,497, the highest figure reported except that for 1925. The chief items sold are wall plasters and wall and plaster board, each of which amounts to over two and one-half millions of dollars in value.

Limestone production shared the increased output noted in other branches of the industry, owing chiefly to the large use of crushed stone for concrete roads and buildings and road metal. The value of this class of material rose from $599,490 in 1926 to $839,463 in 1927. The next most important use of limestone is for agriculture, and $156,069 worth was sold in 1927.

Production of sand and gravel increased 1,279,161 in tonnage and $270,170 in value. This increase was chiefly in gravel and may be accredited largely to road building activities. Prices for most uses ranged from 36 cents to $2.27 per ton, the former being the price realized for paving sand and the latter for cutting sands.

So far as statistics for 1928 have been received they show increased production in nearly all parts of the mineral industry. Cement and limestone experienced a noteworthy impetus and coal mining apparently is recovering from the severe setback of the biennial strike. Gypsum manufacture, however, underwent a serious reaction, both in amounts calcined and in prices received.

The following table shows data for the years 1926, 1927, and 1928:

Mineral Production, 1926 to 1928

	1926		1927		1928	
Product	*Quantity*	*Value*	*Quantity*	*Value*	*Quantity*	*Value*
Cement, bbls.	4,788,639	$ 8,167,341	5,661,234	$ 9,124,405	6,880,731	$10,734,838
Clay wares		4,495,088		5,194,780		5,048,654
Coal, tons	4,625,487	14,214,000	2,949,622	9,304,000	3,683,635	10,525,000
Gypsum, tons	683,201	6,588,203	723,942	6,718,497	719,736	5,355,214
Stone and lime, tons	944,371	952,141	1,278,056	1,267,033	1,668,727	1,761,908
Sand and gravel, tons	2,701,982	1,569,006	3,981,143	1,839,176	3,423,619	2,094,955
Totals		$35,985,779		$33,442,891		$35,520,569

Respectfully submitted,

GEORGE F. KAY,
State Geologist.

THE PRE-ILLINOIAN PLEISTOCENE GEOLOGY OF IOWA

by

GEORGE F. KAY AND EARL T. APFEL

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THE PRE-ILLINOIAN PLEISTOCENE GEOLOGY OF IOWA

PREFACE

Iowa has long been known to be one of the important areas in the world for the study and interpretation of glacial deposits of Pleistocene age. More than thirty years ago Chamberlin, McGee, Leverett, Calvin, and other students of glacial geology found within the state and in adjoining states tills and related materials which were interpreted to have been made in five glacial stages and four interglacial stages. The results of their investigations are to be found chiefly in publications of the United States Geological Survey, the Iowa Geological Survey, the Iowa Academy of Science, and in geological journals and magazines.

The five glacial stages from the oldest to the youngest are known generally as the Nebraskan, the Kansan, the Illinoian, the Iowan, and the Wisconsin; the interglacial stages in the same order of age are the Aftonian, the Yarmouth, the Sangamon, and the Peorian. The deposits made during a glacial stage are drift deposits, those made during an interglacial stage are interglacial deposits.

The three youngest drifts, the Illinoian, the Iowan, and the Wisconsin, and their associated materials have been studied in considerable detail in Iowa and adjacent states, and comprehensive reports of the investigations are available. Although much has been published on the two oldest drifts of Iowa, the Nebraskan drift and the Kansan drift, and on the deposits of the Aftonian and Yarmouth interglacial stages, there has not been prepared thus far any detailed report in which this pre-Illinoian part of the Pleistocene of Iowa has been described and interpreted in relation to the state as a whole.

It is the purpose of this paper to present the results of extensive field and laboratory studies made with special reference to the pre-Illinoian glacial and interglacial deposits. Some conclusions have been reached which differ from those of previous workers, and some new criteria have been found which aid in the interpretation of the complex history of the early part of the glacial period. The paper has been written with the hope that it will be of interest not only to students of Pleistocene geology but to the general reader as well.

INTRODUCTION

The State of Iowa* is located near the middle of the North American continent (figure 1). It is a prairie state, lying in the upper Mississippi valley, between the approximate latitudes of 40° 20′ and 43° 30′ north, and the longitudes 90° and 96° 30′ west. The state is bounded by Mississippi river on the east, by Missouri and Big Sioux rivers on the west, and by commission-determined boundaries on the north and south. Iowa adjoins Minnesota on the north, Wisconsin and Illinois on the east, Missouri on the south, and Nebraska and South Dakota on the west. The area of the state is 55,586 square miles or about 143,967 square kilometers. Its greatest length east and west is 335 miles, its width 208 miles.

The present surface of Iowa is the result chiefly of the uneven mantling of an indurated rock surface by glacial drift. During the long time which followed the formation of the latest of the indurated or hard rocks of the state there was developed a topography characteristic of a mature erosional surface, with broad valleys, moderate slopes, and complete drainage systems. Then widespread climatic changes brought into existence a continental ice sheet to the north of Iowa. The margin of this ice mass was pushed southward until all the area which is now Iowa was included within the ice field. The movement of this great mass of ice resulted in planing off some of the higher lands and filling up the lower lands so that when the ice melted the surface uncovered was very different from that over which the ice had advanced. During four later times parts of this same territory were invaded by the marginal extensions of continental ice fields, and each time a part of the surface of the state was modified as a new drift was deposited. After each ice sheet had been melted off by the recurring moderate climatic conditions the agents of weathering set about to alter the new surface of the land. The materials subjected to weathering were different from the materials at the surface in preglacial times. Instead of hard rocks, such as limestones, sandstones, and shales, the surface was un-

* A geographic map of Iowa, Plate I, is included in this report for convenient reference.

derlain by boulder clays or tills, sands, and gravels, all of which were much more easily altered than the hard rocks. The leveling action of advancing ice, the deposition of drift in valleys and on intervening divides, the weathering, erosion, and redeposition of drift and hard rock materials by water and by wind have all contributed to make Iowa today—in places flat, in places gently

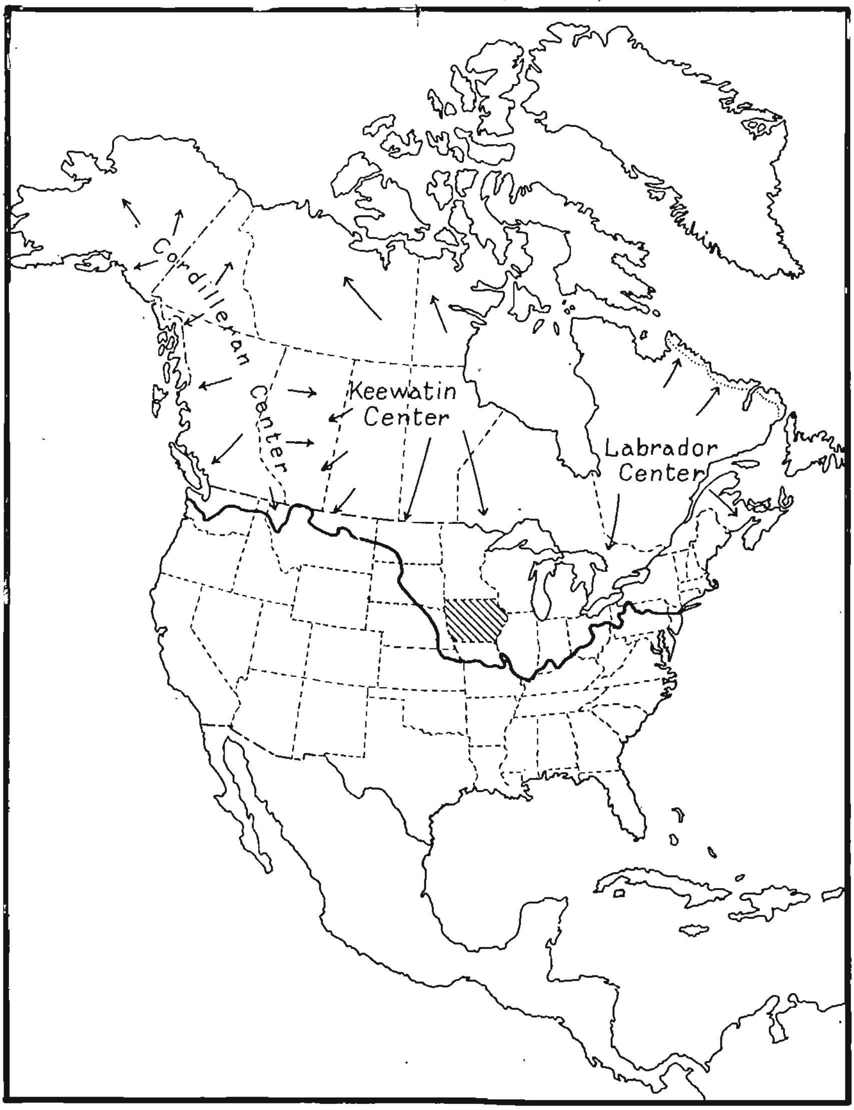


FIG. 1.—Pleistocene map of North America showing the location of the state of Iowa within the glaciated area.

rolling, and in somewhat limited areas rocky, rugged, and picturesque.

Our knowledge of the Pleistocene of Iowa is the result of field and laboratory studies of many persons extending over more than forty years. Little by little the complex but fascinating history of the glacial and interglacial deposits of the state has been unraveled until now there is general agreement among students of glacial geology with regard to the origin and significance of the different materials.

At first the history was thought to have been comparatively simple. The most prevalent view was that there had been but one advance of the ice and one retreat; then came the advocates of the duality of the glacial period; still later came the supporters of three glacial epochs, then four, and finally evidence was thought to be sufficient to justify the interpretation that there had been five glacial epochs separated by important interglacial epochs. The history of the investigations, the work of persons who made important contributions to our knowledge of glacial deposits, and the development of our present classification of the glacial and interglacial materials will be discussed in considerable detail in later chapters of this report. Here reference will be made only to some general facts.

The oldest drift, the Nebraskan, which it is thought may be equivalent in age to drift called Jerseyan in New Jersey and Albertan in northwest Canada, is believed to have completely covered Iowa, including the "Driftless Area" of the northeastern part of the state. It consists of boulder clay or till with associated sands and gravels. Nebraskan gumbotil, which is a very sticky, tenacious clay and is the result chiefly of the chemical weathering of till, separates in many places the Nebraskan till from the till which was deposited by the second ice sheet, the Kansan. This gumbotil was formed between the time of the retreat of the Nebraskan ice sheet and the advance of the Kansan ice sheet, that is, within the Aftonian interglacial epoch. In some places sands and gravels, and in other places peat, instead of gumbotil, separate the Nebraskan till from the Kansan till. The exposures of Nebraskan drift are limited because over wide areas this drift is buried beneath deposits of later ice invasions (see

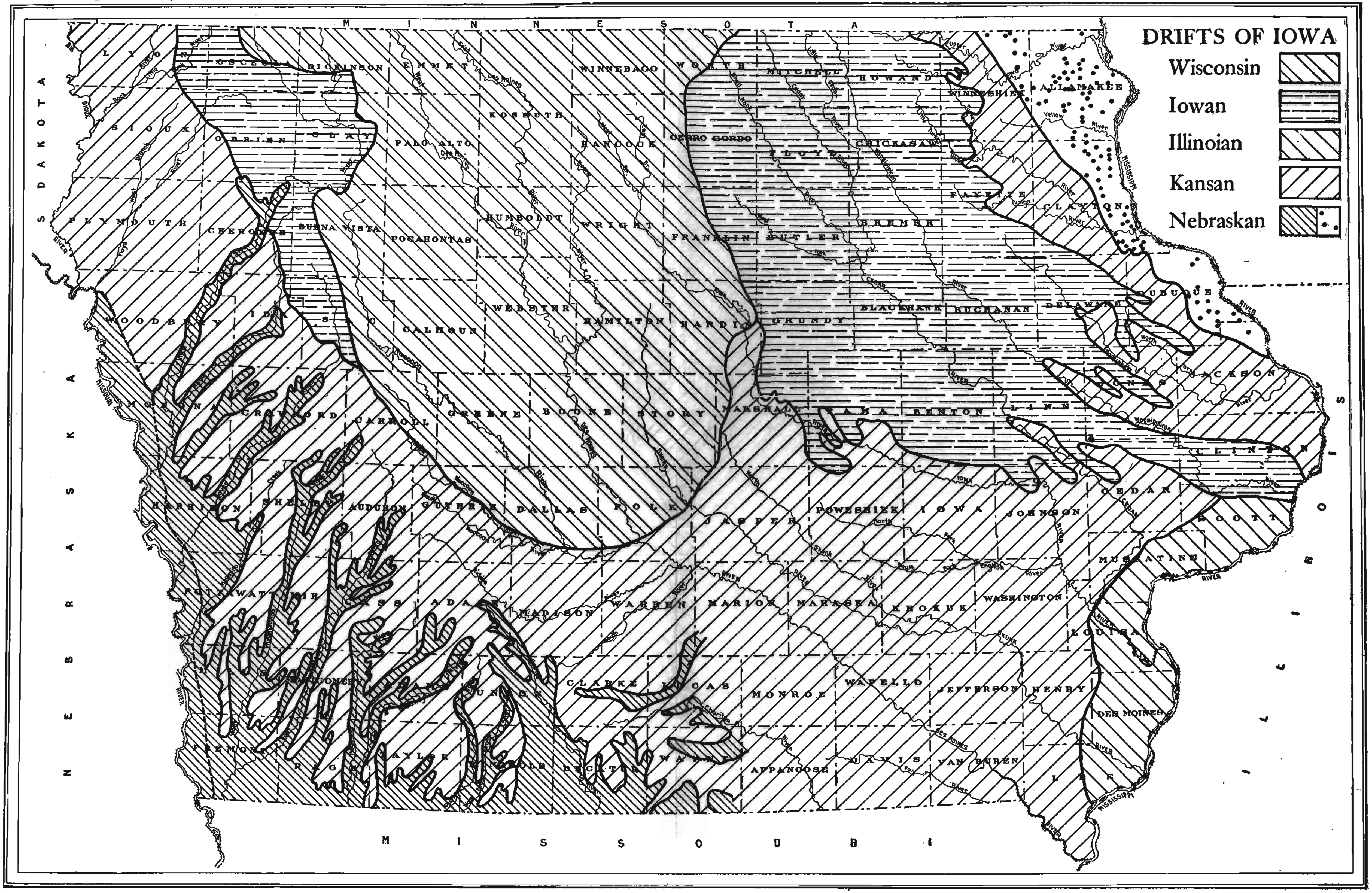
Plate II). The Nebraskan ice sheet which covered Iowa had its origin in the Keewatin field west of Hudson Bay (see figure 1).

The Kansan drift covers all of Iowa except a limited area in the northeastern part which has been called the "Driftless Area." The Kansan drift, too, consists chiefly of boulder clay or till with associated sands and gravels. Lithologically and in other respects this drift in most places resembles closely the Nebraskan drift. The Kansan ice sheet had its origin also in the Keewatin center. Over nearly half of Iowa this Kansan drift was never covered by younger drift (see Plate II). Between the time of retreat of the Kansan ice sheet and the advance of the third or Illinoian ice sheet, that is, during the Yarmouth interglacial epoch, Kansan gumbotil with an average thickness of more than eleven feet was formed over wide areas on the Kansan till. During this Yarmouth interglacial epoch sands and gravels were deposited in some places and in other places peat was developed. Moreover, a mature erosional topography was formed on the Kansan after the gumbotil was developed and before the invasion by the third ice sheet, the Illinoian.

The Illinoian drift covers, in Iowa, a comparatively small area in the southeastern part and is the result of an ice invasion from the Labrador center. It has a fairly distinct marginal line and a more youthful topography than the Kansan. On this till on the level uplands there was developed during the Sangamon interglacial epoch a gumbotil with an average thickness of more than three feet.

The Iowan drift covers the north-central third of the state and is exposed also over an area in northwestern Iowa. It is a thin drift with a gently rolling mantled erosional topography. In contrast to the Nebraskan, the Kansan, and the Illinoian tills, no gumbotil has been developed on the Iowan, but where not overlain by loess it is leached to an average depth of about five feet. On the surface of the Iowan there are many large granitic boulders. During the Peorian interglacial epoch much loess was deposited at the borders of the Iowan on the Illinoian, the Kansan, and the Nebraskan drifts and this loess is the surface deposit now found over the greater part of the state.

The youngest of the five drifts, the Wisconsin, is limited in Iowa to the northwest central part of the state. It is not loess



MAP OF IOWA

Scale 1/1000000
10 0 10 20 30 40 50 Miles

Map showing the surface distribution of the five drift sheets in Iowa covered. The topography is constructional and all the features of youth are retained. On this drift there are lakes, ponds, and marshes, many of which in recent years have been artificially drained. Plate II shows the areal distribution of the five drifts.

For the last eighteen years the senior author, in his capacity of State Geologist of Iowa, has been interested in the study of these glacial deposits of the state, especially the pre-Illinoian deposits with which this report particularly deals. The junior author has assisted in the field studies since 1923 and as research assistant in Pleistocene studies at the University of Iowa he has had charge of investigations in the sedimentation laboratory.

The field studies in recent years have been especially fruitful as a result of construction work which has made available cuts and exposures along the roads of the state. At the close of 1928 there were over 15,000 miles of graded roads. This road work, supplemented by recent work in straightening and regrading some of the railroad lines of the state, has revealed evidence not previously available for study. This evidence has thrown new light upon the characteristics and relationships of the tills, gumbotils, gravels, and other features of the Pleistocene of Iowa.

CHAPTER I

THE BEDROCK SURFACE OF IOWA

The surface rocks of Iowa are all of sedimentary or modified sedimentary origin. The igneous and metamorphic rocks underlying these sedimentary rocks are known only from cuttings of deep wells drilled through the upper rocks; they have had no influence in the development of the erosional surfaces of Iowa. Sedimentary rocks are of two very different kinds, namely, consolidated or indurated rocks and unconsolidated or mantle rocks. The rocks older than the glacial deposits, that is, the pre-Pleistocene rocks, are almost wholly indurated rocks, whereas the glacial and recent deposits are nearly all unconsolidated rocks.

If the drift—the glacial material of Pleistocene age—were removed from the state, the bedrock would then be exposed nearly everywhere. The subdrift surface to be considered in this chapter is the surface of indurated or hard rocks and not the surface of the unconsolidated deposits.

The Indurated Rocks

The indurated rocks of Iowa are chiefly sandstones, shales, limestones, and dolomites, as is shown in the general section of the rocks, given below. The composition, degree of cementation,

GENERAL SECTION OF IOWA STRATA

Group	System	Series	Formation	Character
CENOZOIC	Recent			Soil, geest, alluvium
CENOZOIC	Quaternary, patches of Tertiary	Pleistocene	Wisconsin	Bowlder clay
			Peorian	Loess, forest bed, sand, gravel
			Iowan	Bowlder clay
			Sangamon	Gumbotil, soils, forest bed, sand, gravel
			Illinoian	Bowlder clay
			Yarmouth	Gumbotil, peat, soil, sand, gravel
			Kansan	Bowlder clay, gravel
			Aftonian	Gumbotil, peat, soil, gravel
			Nebraskan	Bowlder clay, gravel
MESOZOIC	Cretaceous	Upper Cretaceous	Colorado	Shale, limestone
			Dakota	Sandstone
PALEOZOIC	Permian	Fort Dodge		Gypsum, shale
	Pennsylvanian	Missouri	Wabaunsee Shawnee Douglas Lansing Kansas City	Limestones, shales, coal
		Des Moines	Pleasanton Henrietta Cherokee	Shales, coals, sandstones, limestones
	Mississippian	Iowa Series: Meramec	Ste. Genevieve (Pella) St. Louis Spergen Warsaw	Limestones, marls, sandstones
		Iowa Series: Osage	Keokuk Burlington	Limestones
		Iowa Series: Kinderhook		Shale, limestones
	Devonian	Upper Devonian	Lime Creek—State Quarry	Shale, limestones
			Cedar Valley	Limestone, shale
			Wapsipinicon { Davenport	Limestone
			Wapsipinicon { Independence	Shale
			Wapsipinicon { Otis	Limestone
	Silurian	Cayugan?	Salina ? nowhere exposed	Limestone, gypsum
		Niagaran	Gower Hopkinton	Dolomites
		Alexandrian	Waucoma	Limestone
	Ordovician	Cincinnatian	Maquoketa	Shale, dolomite
		Mohawkian	Galena	Dolomite
			Decorah	Shale, limestone
			Platteville	Limestone, shale
		Canadian	Glenwood	Shale
			St. Peter	Sandstone
			Prairie du Chien { Shakopee	Dolomite
			Prairie du Chien { New Richmond	Sandstone
			Prairie du Chien { Oneota	Dolomite

Group	System	Series	Formation	Character
	Cambrian	Croixan	Jordan	Sandstone
			St. Lawrence { Trempealeau	Dolomite, marls
			St. Lawrence { Franconia	Shale, glauconite, marl
			Dresbach	Sandstone
			Eau Claire (Not exposed in Iowa)	Shale, sandstone
			Mt. Simon (Not exposed in Iowa)	Sandstone, shale
			Red clastic beds (unnamed) (Not exposed in Iowa)	Sandstone, shale, conglomerate
PROTEROZOIC	Algonkian	Huronian	Sioux	Quartzite
ARCHEOZOIC	Laurentian?		Nowhere exposed	Granite, schist

and other physical characters largely determine the relative resistances of these rocks to weathering and transportation by water, wind, and moving ice. The indurated rocks were overridden by ice sheets and an effort has been made to evaluate the relative resistances of the various formations to erosion. The judgment reached is indicated in figure 2.

The Proterozoic Rocks—The Sioux Quartzite.—The oldest bed rock beneath and in contact with the drift of the state is the Sioux quartzite of Algonkian age. This fine-grained, compact, strongly cemented quartzite outcrops over a few acres only in the northwest corner of Iowa, but it has a fairly wide distribution in adjacent parts of South Dakota and Minnesota.

The quartzite has several phases, with colors varying from light pink to bluish purple. The quartzite was formed from quartz sand by the growth of the grains by the addition of oxide of silicon until the grains interlocked to form a very hard siliceous rock. Some of the Sioux quartzite includes feldspar and hematite or other iron oxide. As glacial boulders the Sioux quartzite is a prominent and characteristic feature of the drift in the western two-thirds of the state. Sioux quartzite is much jointed, but it is very resistant to abrasion and to chemical weathering. Where it outcrops over large areas it has a fairly rugged topography; in Iowa its area is small and hence it has had a subordinate influence on the topographic development of the state.

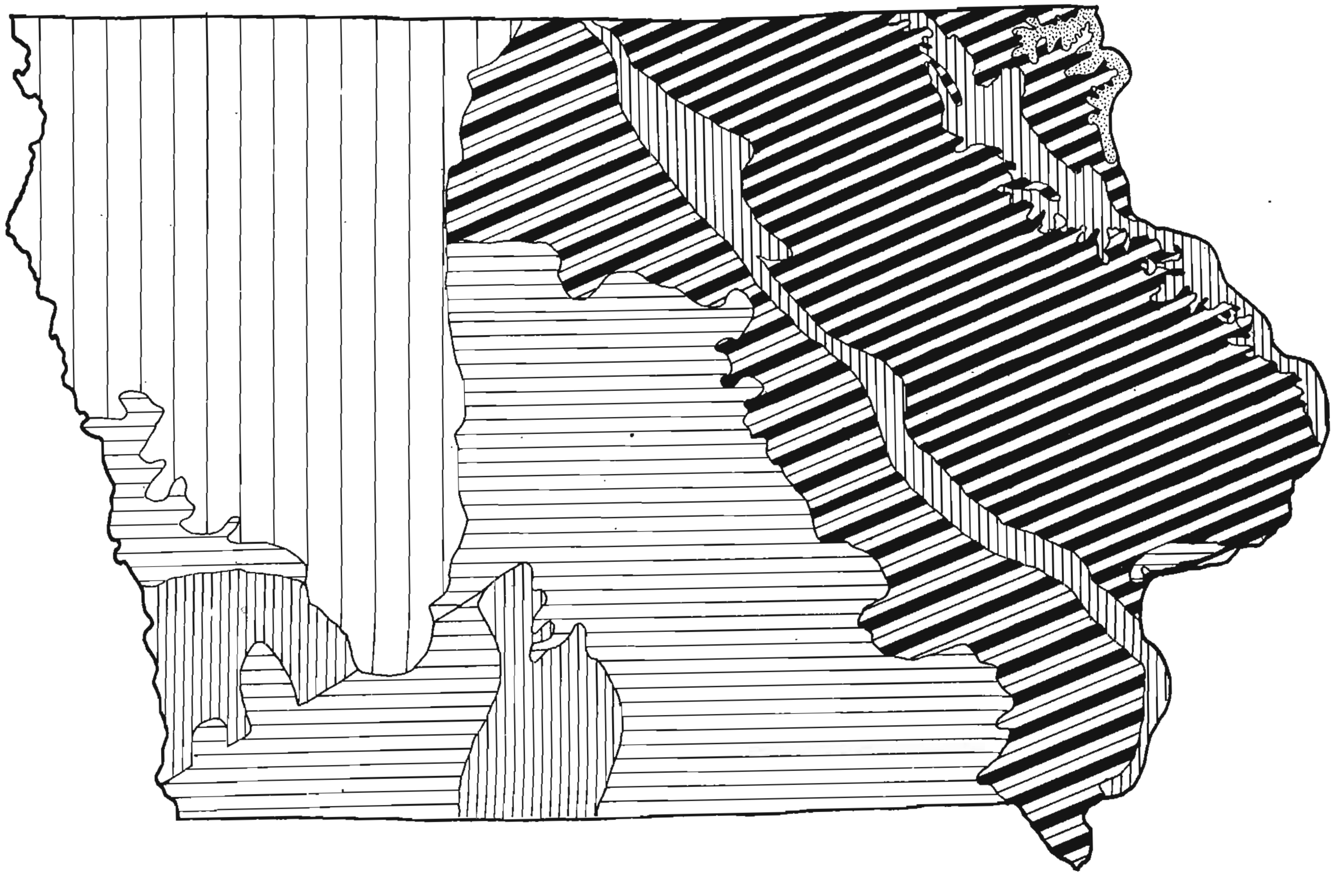


FIG. 2.—Map of Iowa showing by density of pattern the relative resistances of various areas of rocks to erosion. Areal boundaries are generalized as far as possible on the basis of the controlling rock.

The Cambrian System—The Croixan.—Cambrian rocks are exposed in Iowa only in the northeast corner. They are dominantly sandstones, but there are also some shales and dolomites in thin beds. These Cambrian rocks occur almost entirely within the so-called "Driftless Area"; they outcrop only where the drainage lines have cut deeply below the uplands; and the outcrop pattern closely parallels the pattern of the drainage. These rocks in general are not strongly cemented and hence are only moderately resistant to erosion. They are of minor significance in the study of the erosional history of the state.

The Ordovician System.—Ordovician rocks outcrop in a northwest-southeast belt in the much dissected "Driftless Area" in the northeast corner of Iowa and also lie under part of the thicker drift area farther west. The formations include about 370 feet of dolomite, 290 feet of shale, 240 feet of limestone, and 120 feet of sandstone, a total of more than 1,000 feet of indurated rocks. The maximum width of the belt of these rocks at the surface is about 40 miles.

The topography of the Ordovician area indicates in a general way the resistance to erosion of these formations. The dolomites, limestones, and some of the sandstones form bluffs and cliffs along the valley walls; also they form cores of hills now drift covered and thus they influence the drift topography. Long gentle slopes and rounded hills indicate the presence of underlying shales and sandstones.

None of the Ordovician formations are uniformly lithologically distinctive enough to be identified as fragments in the drift except where fossiliferous. Certain formations contain lead and zinc ores locally and these may aid in the identification of formations when fossils are wanting. Both the Nebraskan and Kansan ice sheets crossed Ordovician rocks, which furnished part of the load which was deposited later as drift.

By way of summary, it may be stated that within the restricted belt of Ordovician rocks, the shales and some of the sandstones are weaklv resistant to erosion, whereas the dolomites and limestones and some of the sandstones are moderately resistant.

The Silurian System.—The Silurian system consists of the Alexandrian series and the Niagaran series. The former is so limited in distribution that it does not merit consideration here.

The Niagaran is a buff-colored resistant dolomite, which is exposed in a triangular area near the middle of the east side of the state. An overlap of Devonian to the north restricts the present northerly and northwesterly surficial extension of the Niagaran.

Where thinly drift covered, the area of the Niagaran is marked by many outcrops, steep slopes, and V-shaped valleys. Where more heavily drift mantled, the rock is exposed in many river gorges cut through the drift and into the buried ridges of the hard rock which were unreduced before being drift covered.

With the exception of the Sioux quartzite, the Niagaran dolomite was the most resistant to glacial erosion of any major rock series in the state.

The Devonian System.—The Devonian rocks of Iowa outcrop in a wedge-shaped belt across the eastern half of the state. The northern end of this area is the broader, and here the rocks overlap with prominent unconformity the Silurian and the Ordovician. The stratigraphy of the Devonian is difficult to correlate over wide areas owing to the presence of many small unconformities within the system.

The rocks of the Devonian of Iowa are chiefly limestones and dolomites. Locally, shale members are present but they are limited areally. Fossiliferous limestones, lithographic limestones, and breccias, of Devonian age, when found in the drift are easily recognized. A thick drift above these indurated rocks reduces their influence on the topography. The limestones are fairly resistant to erosion, but the shales are weakly resistant.

The Mississippian System.—The Mississippian system in Iowa includes rocks outcropping in a northwest-southeast belt immediately west of the Devonian rocks. The erosional unconformity above the system and the overlap of the Pennsylvanian deposits cause the outcrops of the upper members to be patchy and discontinuous. The rocks differ lithologically in different formations and within the same formation; nor are the formations continuous over large areas.

The lowest formation, the Kinderhook, is chiefly shale with lenses of sandstones and limestones. It is weakly resistant and exerts its influence upon about one-half of the Mississippian surface. The Osage, Meramec, and Ste. Genevieve are chiefly limestones with some interbedded sandstones and shales. These rocks are moderately resistant to erosion.

The Mississippian rocks, like the Devonian, are for the most part buried under a thick drift and many fragments of Mississippian rocks are found in the drift. These formations influence only subordinately the present topography of the state.

The Pennsylvanian System.—The Pennsylvanian rocks are divided into two series, the Des Moines or Lower Coal Measures and the Missouri or Upper Coal Measures. The Des Moines rocks are beneath the drift in the south-central part of the state and the Missouri rocks are the chief indurated rocks in the southwestern part of Iowa.

The Des Moines series consists chiefly of shales in the lower part and limestones interbedded with coal and shale in the upper part. Although some members are resistant, the series as a whole is relatively weakly resistant to erosion.

The Missouri series consists of interbedded calcareous shales and limestones which are fairly uniform in character over large areas. The limestones are fairly resistant to erosion, but the shales are weakly resistant to erosion.

The Permian System.—The Permian rocks occupy a small area in Webster county, which is in the central part of the state. The rocks are mostly shales and gypsum and are weakly resistant.

The Cretaceous System.—The Cretaceous rocks of Iowa belong to the Dakota and the Colorado series. They are found in the northwestern and western parts of the state, overlapping rocks as old as Mississippian in age. Almost everywhere the Cretaceous rocks are mantled deeply by drift.

The older Cretaceous rocks, the Dakota, are dominantly sandstones with interbedded seams of clay. The weak cement contains much iron, and the sandstone is friable. The younger rocks, the Colorado, consist of weak shales and calcareous beds with a maximum thickness of about 150 feet.

Norton describes the Cretaceous from the well records as occurring in "more or less isolated patches whose borders can seldom be determined." The Cretaceous is mapped as continuous over the area where such patches occur, although rocks of this age may not be everywhere present. The Cretaceous rocks are weakly cemented, and hence are among the least resistant rocks of the state.

The Tertiary System.—A minor deposit, unmapped areally, is the Windrow formation, described by various authors as the "High Level Gravels." The age of these gravels is indefinite; some persons interpret them to be Tertiary, others to be Cretaceous in age. The distribution of this formation is very erratic, owing perhaps to deposition of the gravels on valley floors which are now comparatively much elevated through the general reduction of surrounding areas.

The Windrow materials are quartz and chert pebbles in a matrix of sand, the whole in most places cemented by either brown or red iron oxide. Most of the deposits are weakly or not at all consolidated, and hence yield readily to abrasion. The contribution of this material to the drift is indeterminable.

Structure of the Rocks

The structure of the Paleozoic rocks in Iowa is that of a broad, shallow, wrinkled trough or synclinorium with the axis extending in a general northeast-southwest direction between opposite corners of the state and dipping to the southwest. The higher edges of the tilted rocks have been eroded to a surface with much less slope than that of the bedding planes of the rock strata. The result is that successively younger formations are exposed from the northeast corner to the southwest corner of the state, in belts with a northwest-southeast direction, roughly parallel to the strike of the rocks.

On the upturned edges of these Paleozoic formations the Permian and Cretaceous rocks were deposited unconformably.

The major structure of the rocks is a syncline, but there are many minor structural features which were formed during and after the development of the large syncline. Some of these are small synclines and anticlines. There are also many small faults, in few of which the differential movement of the two sides exceeds a hundred feet. All these features contribute to complicate the pattern of the outcrops of the different rock formations.

Unconformities.—The unconformities or buried erosional surfaces also exerted an influence in the development of the rock outcrops. These unconformities involve times of erosion between the deposition of the rocks below the unconformities and the rocks which lie above them. The greatest unconformity in the state is between the Sioux quartzite of Proterozoic age and the Cretaceous of Mesozoic age. It is probable that rocks younger than the Sioux quartzite were deposited over the Sioux quartzite area and that they were eroded previous to the deposition of the Cretaceous. Other great unconformities are between the Silurian and the Devonian rocks, the Mississippian and the Pennsylvanian, the Permian and the underlying Mississippian and Pennsylvanian rocks, and between the Cretaceous rocks and the rocks on which they lie. Many smaller unconformities occur between various formations of different systems in the state. After the latest indurated rocks of the state were deposited there was developed an erosion surface over which the first ice sheet advanced and on which glacial drift was deposited.

The great syncline, the smaller synclines and anticlines, the faults, the unconformities, differential erosion, and other factors all have contributed to make the relationships which now exist among the many formations of the state. The geologic map of Iowa, figure 3, represents the areal distribution of the various rocks which constitute the bedrock surface of the state. The boundaries are necessarily somewhat generalized, chiefly because they are not definitely determinable below the mantle of glacial drift.

The Preglacial Bedrock Surface

The preglacial bedrock surface of Iowa was developed by erosion during the long time between the withdrawal of the Cretaceous seas and the advance of the first ice sheet into Iowa. The first ice sheet left a mantle of drift which in many places protected the bedrock surface from further erosion and the deposits of succeeding ice sheets still more deeply covered the rocks. Under such conditions, how is it possible to determine the topography and relief of the bedrock surface? Well data must be relied upon largely, and since such data are not available except in a comparatively limited number of places, a detailed topographic map of the bedrock surface cannot be made.

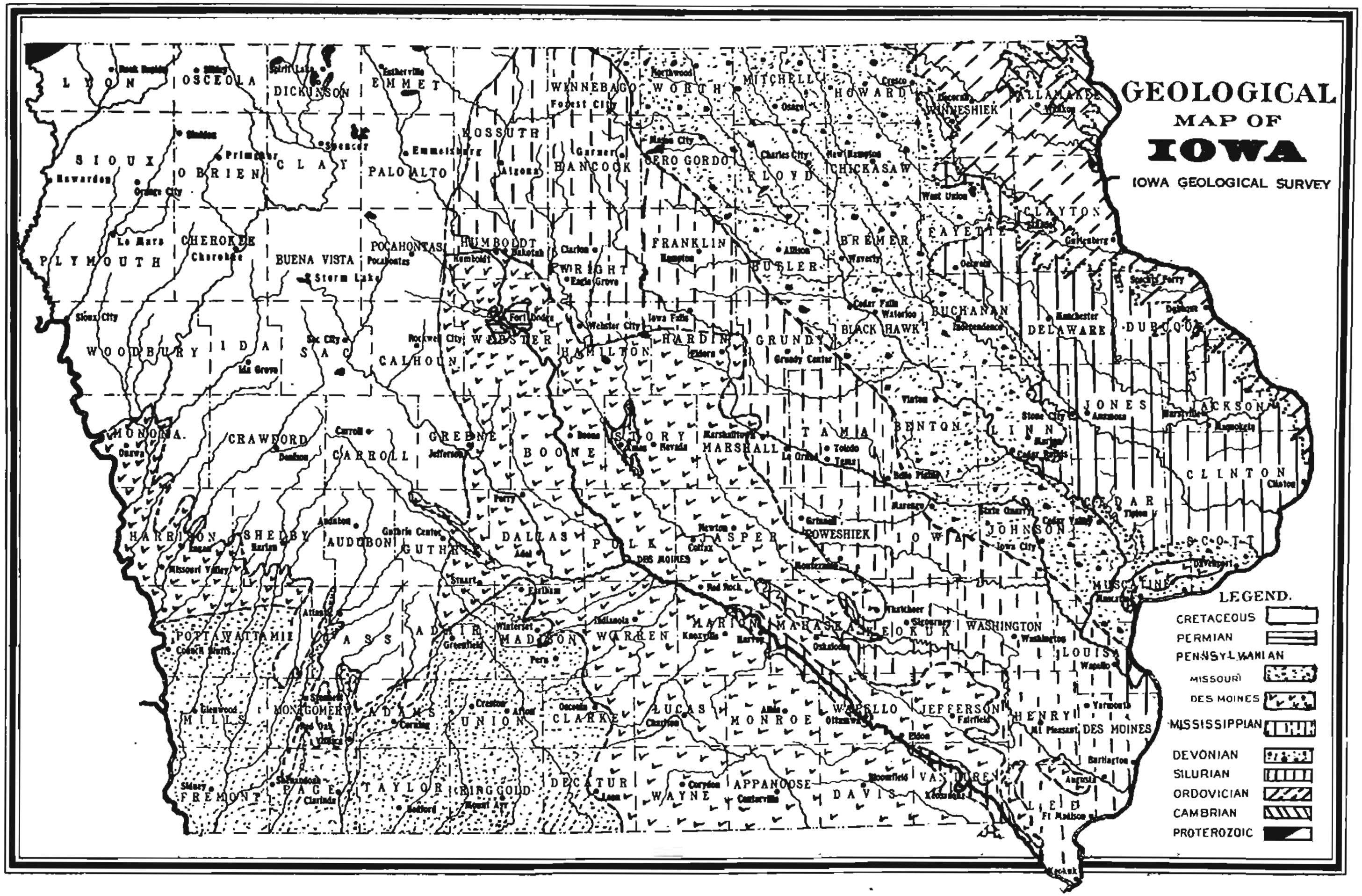


FIG. 3.—Geologic map of Iowa.

However, in Iowa, fortunately enough, sufficient evidence is available to warrant some conclusions with respect to the character of this bedrock surface. How interesting it would be if it were possible to trace the evolution of the bedrock surface from the beginning of its development to the present time!

The character of the bedrock surface will be described and its history interpreted insofar as the information at hand would seem to justify. The rock surface beneath the drift in Iowa has a general gentle slope across the state, and this slope is locally intrenched by valleys cut in the rock before, during, and since the invasion by the ice.

The highest rock recorded in the state is near the northwest corner. From this area the general rock surface slopes gently and fairly uniformly in easterly, southerly, and southeasterly directions to near the middle of the state, where there is a distinct sag. From the lowest part of this sag the surface rises eastward to the uplands in the northeastern part of the state.

The general slope of the rock surface is so slight that if the valleys were filled to the levels of the general plain this slope could not be detected by the eye. This indicates the great planation which brought all the surface to the same general level. The following figures indicate approximately the slopes of the rock surface. They represent the mean of the highest elevations above sea level found in each part of the state considered.

TABLE OF ROCK SURFACE SLOPES IN IOWA

NW. corner (1250 ft.) to the NE. corner (1200 ft.). Fall of 50 feet in 250 miles. There is a sag down to 1050 feet between these two points.

NW. corner (1250 ft.) to the SW. corner (1000 ft.). Fall of 250 feet in 200 miles.

NW. corner (1250 ft.) to the SE. corner (650 ft.). Fall of 600 feet in 300 miles.

SW. corner (1000 ft.) to the SE. corner (650 ft.). Fall of 350 feet in 250 miles.

NE. corner (1200 ft.) to the SE. corner (650 ft.). Fall of 550 feet in 200 miles.

Middle of north border (1100 ft.) to middle of south border (850 ft.). Fall of 250 feet in 200 miles.

NE. corner (1200 ft.) to near Des Moines (900 ft.). Fall of 300 feet in 150 miles.

SW. corner (1000 ft.) to near Des Moines (900 ft.). Fall of 100 feet in 100 miles.

The bedrock surface then is not a level plain but a broad trough with the northwestern and eastern parts of the state forming the sides and with the axis of the trough extending from the north-central part of Iowa to near the southeastern corner. There are of course many small areas which if their elevations were accurately known would show slopes in other directions and

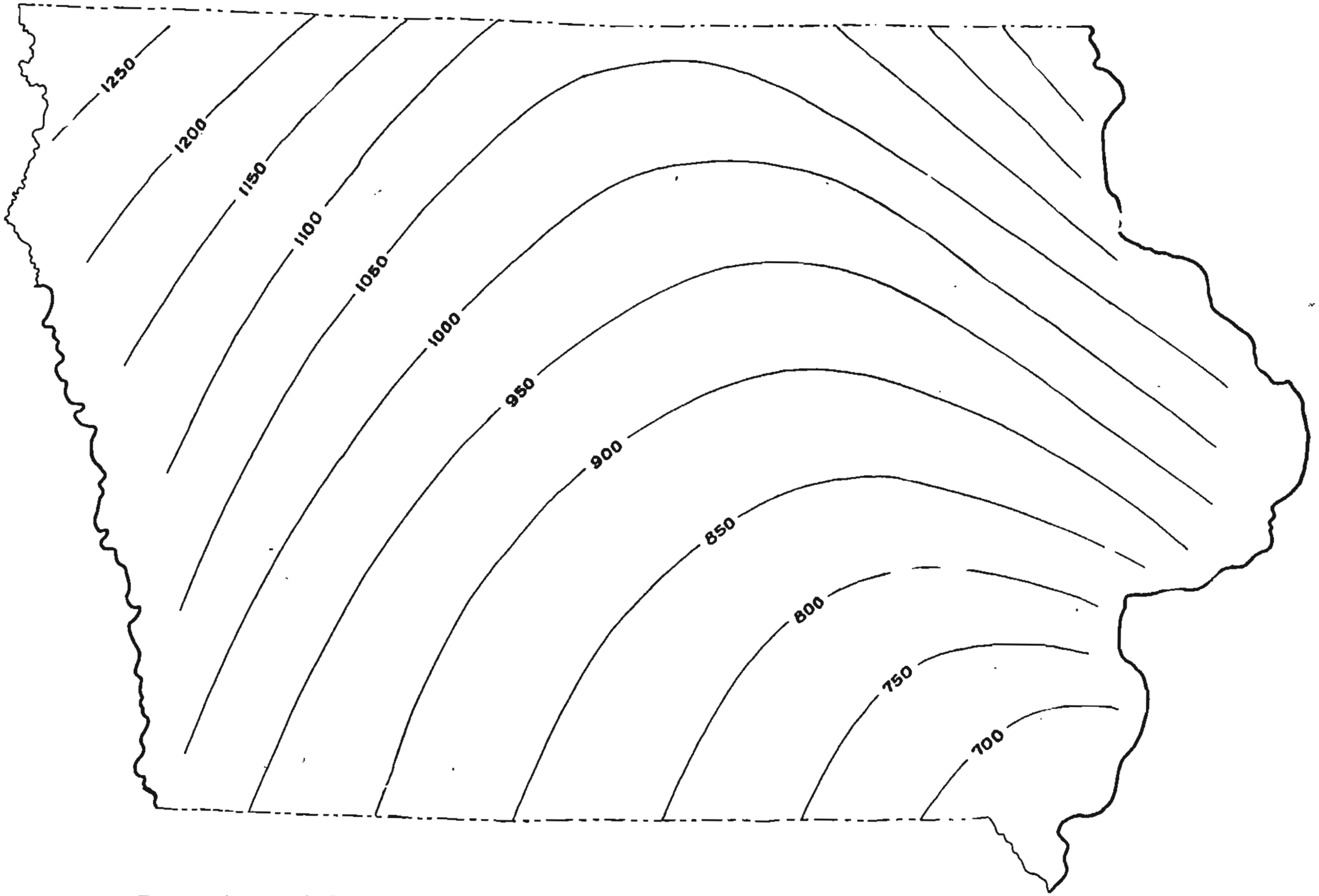


FIG. 4.—A generalized contour map at a 50 foot interval showing the broad sag in the bedrock surface of the state.

would thus reveal the main drainage courses on the preglacial surface and the divides between them.

The general attitude of the rock surface without any of the minor relief features which were cut into it is shown on the accompanying map, figure 4.

When a study of the minor relief features is made in comparatively limited areas, it is found that the differences in elevations between the lowest and highest points on the bedrock are very moderate. The maximum is about 400 feet in county areas and the average is well under 300 feet. The following table gives the reliefs in a number of the counties of the state as found by various workers and the computed reliefs in a number of counties where there are deep subdrift channels in the bedrock.

TABLE OF BEDROCK RELIEF

Amount of relief	*Location*	*Authority*
245 feet	Buried channel in SE. Iowa	Gordon
250 feet	Deep river, Keokuk county	Bain
285 feet	Washington channel, Washington county	Bain and Calvin
324 feet	Washington county	Bain and Calvin
200 feet	NE. corner, Johnson county	Calvin
175 feet	Polk county	Bain
50 feet	Mason City, Cerro Gordo county	Calvin
300 feet	Madison county	Tilton and Bain
100 feet	Lower Skunk river valley	Beyer
300 feet+	Muscatine county	Udden
250 feet	Scott county	Norton
100 feet+	Belle Plaine artesian area	Mosnat
300 feet+	Louisa county	Udden
200 feet	Cedar county	Norton
110 feet	Jefferson county	Udden
367 feet±	Tama county	Savage
300 feet	Clinton county	Udden
234 feet	Iowa county	Stookey
220 feet	Bremer channel, Bremer county	Norton
275 feet	SW. Jackson county	Norton
220 feet	Jones county	Norton
96 feet	Central City, Linn county	Norton
115 feet	Lisbon, Linn county	Norton
260 feet	Scott county	Norton
240 feet	Johnson county	Leighton
204 feet	Cass county	Tilton
300 feet±	Southeast Iowa	Schoewe
120 feet	Des Moines, Polk county	Bain
400 feet±	near Des Moines	Lees
Less than at present	Marshall county	Beyer
Rock foundation even and uniform	Humboldt county	Macbride
Remarkably uniform rock floor	Kossuth, Hancock, and Winnebago counties	Macbride
300 feet±	Crawford county	Lees

The following counties have the bedrock reliefs indicated.

There is in each case a large buried channel which furnishes the minimum elevation.

317 feet	Jasper county	computed
368 feet	Tama county	computed
325 feet	Marshall county	computed
380 feet	Grundy county	computed
363 feet	Poweshiek county	computed
365 feet	Monroe county	computed
291 feet	Madison county	computed

When the known bedrock elevations of limited areas are plotted in relation to the generalized contours of the bedrock of the state (see figure 4), it is seen that they fall well within the range of relief to which reference has just been made. The maximum relief is about 400 feet, with the average somewhat less. An important conclusion is based on these facts, namely, that the relief of the bedrock of the state outside the "Driftless Area" differs from the relief of the bedrock in this area, being 200 to 400 feet less outside the "Driftless Area" than in it. How shall these differences be explained? By Pleistocene erosion of 200 to 400 feet more rock in the "Driftless Area" than elsewhere? By the planing off of 200 to 400 feet from the areas of the state outside the "Driftless Area" by glacial erosion? Or, by a combination of these and other factors? Suffice it to state here that (a) the abundance of foreign material in the drift of Iowa, (b) the extent of undisturbed surfaces of older drifts which have been overridden by glaciers, (c) the absence of deep grooves and striæ on rock surfaces, (d) the persistence of abrupt rock walled gorges in areas which were glaciated, (e) the fact that the ice sheets advanced over areas which had long been subjected to weathering, and hence covered with much material available for transportation, suggest strongly that the ice sheets were well loaded when they invaded Iowa, and although their planing action in places may have been great the relative reduction of the relief of the surfaces probably was inappreciable. Furthermore, (a) the young gorge of Mississippi river, (b) buried, discontinuous, steep-walled rock-bound valleys, and (c) the presence of Nebraskan drift only on the uplands in the so-called "Driftless Area" of Iowa indicate extensive erosion subsequent to the first ice invasion. Study of the various kinds of evidence justifies the conclusion that post-Nebraskan, pre-Kansan erosion will account for the difference between the bedrock relief of the subdrift areas of Iowa and the relief of the "Driftless Area."

Buried Rock Valleys.—From a study of well records some interesting facts have been revealed about some steep-walled, drift-buried rock gorges of the state. Such gorges have been described as occurring in more than twenty localities in the eastern half of Iowa. Where the directions of these valleys can be traced they have been found to parallel roughly present drainage lines; in fact, some of the present river channels overlie, on drift beds, the old channels. The widths and depths of the old channels are various. The widest channel which has been described fully is the Bremer channel in Bremer county. Norton[1] has shown that this channel is about 2½ miles wide and 250 feet deep in bedrock; it has been traced for about 14 miles. Other channels are smaller and have been traced for greater or less distances. The valley walls as a rule have steep slopes, indicating cliffs and bluffs along the sides when the valleys were open. Many of the larger valleys are described as having "numerous branches" suggesting a well developed drainage system. Some of the smaller channels are only a few score feet in depth and a few rods wide. One of the larger of the small valleys is the Lisbon channel in Linn county, the walls of which have been well defined by drillings within the town of Lisbon. Norton states that the channel has a width of about 18 rods and a depth in bedrock of about 115 feet.

The characteristic features of all the buried channels, large and small, are (a) abrupt rock walls, (b) maximum depth in bedrock of less than 300 feet, (c) limited length, (d) a general northwest-southeast direction. The known buried channels lie in the eastern part of the state.

The preglacial and interglacial channels of Mississippi river have not been referred to here since their discussion belongs more properly in the discussion of the detailed record of Pleistocene history in the areas in which these channels are found.

The less pronounced relief which is revealed in a study of the state as a whole is interpreted to be the pre-Pleistocene topography, whereas the steep-walled, drift-buried valleys which are

[1] Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, Ann. Rept. 1910-1911, pp. 315-319.

distinctive features of the bedrock topography of the state are interpreted to be interglacial in age. They are thought to have been cut chiefly in Aftonian time. The drainage lines on the Nebraskan drift surface removed the drift in places and then by further excavation cut valleys which in some cases lay across pre-Pleistocene bedrock divides. Subsequently glacial deposits filled the gorges, making of them buried valleys of interglacial age.

Summary

In summary, the bedrock history of Iowa may be outlined as follows: At the close of the Cretaceous period the area which is now Iowa was a land surface. The soft Cretaceous deposits were subjected to erosion, and older rocks also were eroded. Erosion during the long Tertiary period brought all the land down to a surface with gentle slopes and a relief of perhaps 200 feet. Such a surface in northeastern Iowa, determined from its remnants, has been named the Dodgeville peneplain. Before the end of Tertiary time changes in the relative elevations of land and sea caused the streams to be rejuvenated and they developed new valleys. At the new grade, the streams widened their valley floors and weathering reduced the wall slopes to form a topography much more rugged than that of the Dodgeville peneplain but still one with moderate slopes and with flat-topped divides at the level of the old peneplain. The new level developed by the streams, which has been named from its remnants the Lancaster peneplain, is about 200 feet below the Dodgeville surface. This relief, added to that on the upper plain, gives a total relief of about 400 feet. Over such a surface came the first ice sheet of the Pleistocene. The melting of the ice left a new surface—a drift surface—superimposed over the bedrock surface. New drainage was inaugurated and during the first interglacial stage, the Aftonian, the moderate thickness of the Nebraskan drift was not sufficient to protect all the rock. Where the new drainage lines crossed the divides of the bedrock surface, the rock as well as the drift was eroded. The second ice invasion, the Kansan, buried the new rock valleys and more deeply covered the pre-Nebraskan surfaces. Both the preglacial and interglacial valleys were given the aspect of pre-Pleistocene channels by the drift filling. Later ice invasions over parts of the state likewise covered valleys cut through the Kansan drift into the bedrock, giving to these still younger gorges pre-Pleistocene erosion features. It is not possible to assign to every feature of the subdrift surface its definite age, but at least two major kinds of valleys may be differentiated.

CHAPTER II

TOPOGRAPHY AND DRAINAGE OF IOWA

General Statement

The topography of an area is its surface configuration. It includes the relief of the land—the differences in elevation between the high and low points of the surface—the shapes and dimensions of valleys occupied by the streams, the drainage pattern, and the characteristics of the slopes. All of these are the result of the activity of two classes of agencies: those tearing down or reducing the surface of the land by erosion, and those building up the surface of the land by deposition. The former are destructional agencies, the latter are constructional. The relative positions of land and sea levels are throughout long periods of time sufficiently stable to provide constant conditions under which agents of erosion and of deposition may operate. But from time to time new adjustments are made, the topographic record of which becomes a part of the geological history of the region.

Iowa is a prairie state, in general having moderate relief and gentle slopes. In some places there are broad uplands, in other places the valley flat is a conspicuous feature. The highest point in Iowa is near the northwest corner of the state in Osceola county west of Sibley. Here the elevation is 1675 feet above sea level. The lowest point is at Keokuk, in the southeast corner of Iowa, where the low water mark of Mississippi river is 477 feet above tide. The highest area of the state lies along the upland which constitutes the southeastern continuation of that wedge-shaped ridge of Minnesota and Dakota known as the Coteau des Prairies.

Iowa lies in the Mississippi valley, between Missouri river and its tributary the Big Sioux on the west and the Mississippi on the east. Tributaries of these streams drain the surface of Iowa, carrying the waters eventually to the Gulf of Mexico. The divide between the Mississippi and Missouri basins lies along a rough arc crossing the north and south borders of the state so that the west one-third of the north part of the state and the west two-thirds of the south part are drained to the Missouri. The divide does not everywhere coincide with the highest area of the state; the divergence between them is indicated on the accompanying sketch map, figure 5.

Nearly two-thirds of the state drains to Mississippi river. Eight tributaries large enough to be called rivers enter this stream from Iowa at unequal distances apart, and numerous creeks drain the small areas between the tributary streams. The larger rivers, from north to south, in the order of their entrance into Mississippi river are: Upper Iowa (Oneota), Turkey, Yellow, Maquoketa, Wapsipinicon, Iowa, Skunk, and Des Moines rivers. All of these rivers have numerous branches which form a network over the drainage basins.

The drainage basins of the main tributaries to the Mississippi are much longer than they are wide, as is shown in figure 5. They show also fairly regular outlines with the lateral boundary lines tending to be parallel. The main extension of the basins is to the northwest, with a gradual swing from a straight line resulting in a bowing to the southwest.

Along Mississippi river, more than three-fourths of the immediate west valley wall is drained directly to the river through creeks, so that the main drainage basins are restricted near the mouths of the rivers, and flare abruptly from 10 to 30 miles above their union with the Mississippi valley proper.

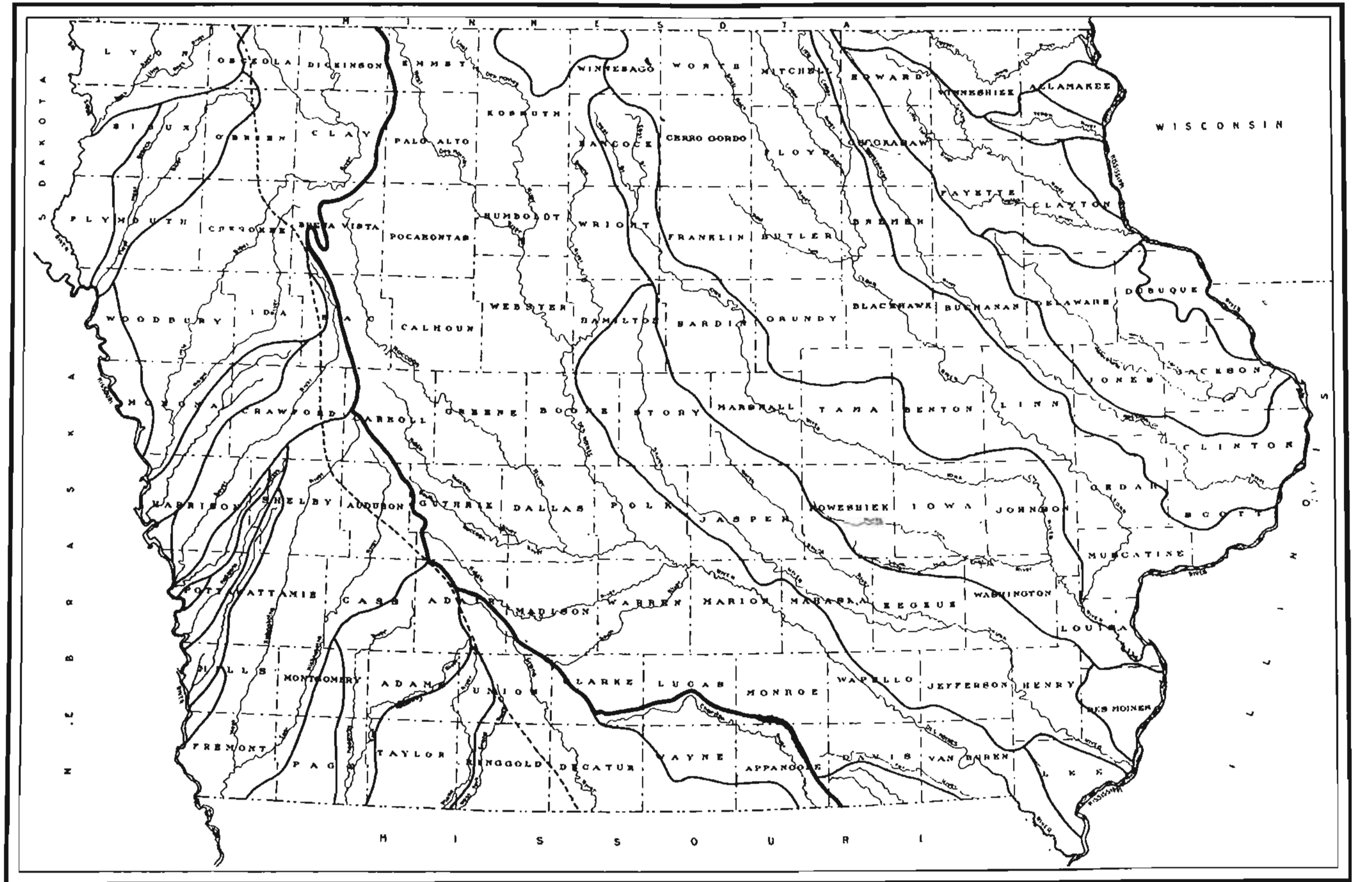


FIG. 5.—Sketch map of Iowa showing outlines of the drainage basins of the state; also the divergence between the height of land as shown by a dashed line and the Mississippi-Missouri river divide as shown by a solid heavy line.

Turkey, Yellow, Maquoketa, and Skunk rivers drain Iowa territory only, whereas the four other main streams carry more or less water from Minnesota, though they head not far north of the Iowa boundary. No streams flow into the state from the south.

The area of Iowa which drains into Missouri river has the shape of a boot, heelless and with the toe facing east along the south margin of the state. The drainage basins in this western region are, as in the eastern region, longer than they are wide, but they tend to be straight and lie nearly at right angles to those of the Mississippi tributaries. There are no large tributaries of the Missouri in Iowa except Big Sioux river, which forms the northern part of the west boundary of the state. The other tributaries are of moderate size, and those which drain the southern part of the state, or the toe of the boot, are the headwaters of streams which flow into the state of Missouri and thence to Missouri river.

About half of the Missouri river basin in Iowa is drained through tributaries which rise in the state and empty into the parent stream before it reaches the southern boundary of the state, and about half is drained through tributaries which enter the state of Missouri before reaching the master stream. A small area in northwestern Iowa is drained by the Big Sioux and by tributaries which rise beyond the borders of Iowa.

As stated before, much of the state of Iowa is well drained by tributaries of the large rivers at its borders. Differences in types of stream valleys, in arrangement and development of tributaries, in perfection of drainage, and in direction of flow, are the result of many factors. These features will be considered in connection with the study of characteristic topographic areas resulting from particular conditions.

Some parts of Iowa show extensive erosion, whereas other parts show little erosion and have distinctive constructional features. With respect to Iowa as a whole, it would be incorrect to assign either erosion or deposition as the more important factor in the development of the topography. However, the causes for the topographies in the various sections of the state can be fairly correctly assigned. The present topography of the state is related very closely in origin to the glacial history of Iowa and therefore it will be discussed here in some detail. On the basis of the major factors which operated to form the topography, the

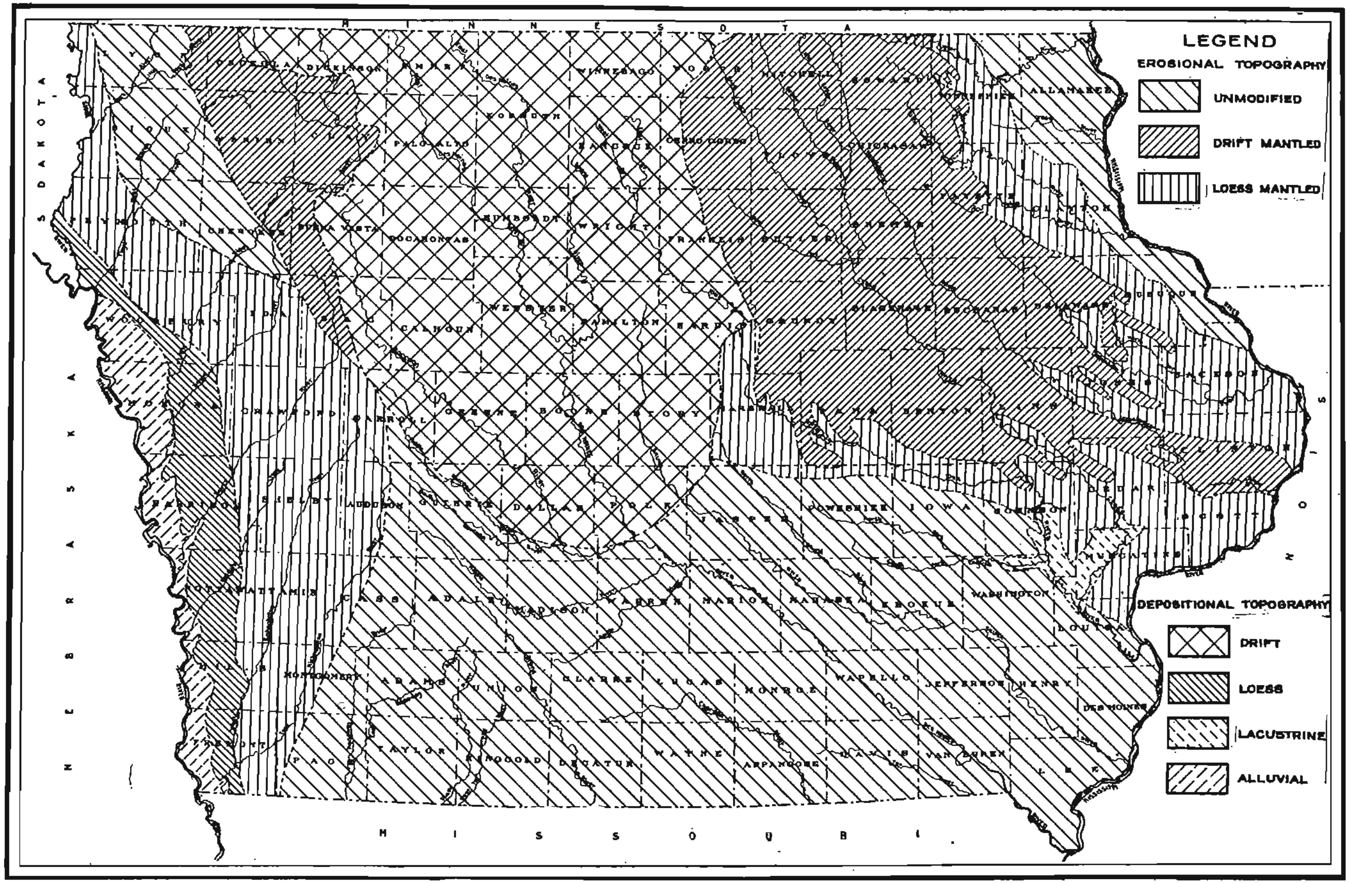


FIG. 6.—Map of Iowa showing by patterns the main areas of distinctive topographic development in the state.

accompanying map, figure 6, has been prepared. The kinds of topography which can be differentiated in Iowa are as follows:

Types of Erosional Topography.—Erosional topography essentially unmodified, drift mantled erosional topography, loess mantled erosional topography.

Types of Depositional Topography.—Drift depositional topography, loess depositional topography, lacustrine depositional topography, alluvial depositional topography.

The areas which have been mapped and which will be described are not sharply distinguishable from one another. The boundary lines are somewhat arbitrarily drawn within transitional zones a few miles in width, in any part of which the lines might almost equally well have been drawn. This is true especially where loess has been a controlling factor. Each type of area will be described to show the characteristic topographic and drainage features peculiar to it.

Types of Erosional Topography

GENERAL STATEMENT

The most potent factor in the reduction of the land is transportation of earth materials by running water. Whenever rain falls on the land some movement of detritus takes place, even though the amount of material moved may be little and the distance it is carried may be short. The whole surface of the land is undergoing slow but extensive modification because of the constant renewal of the surface waters by rains.

The amount of material removed by streams is enormous, and yet the areas of land are so great that the reduction of the total surface is only of the order of about one foot in 9,000 years. The amount of material removed is not the same everywhere; some regions lose much soil and subsoil each year, whereas other areas are not changed appreciably even after many years. This unequal removal of material from different surfaces is the main cause of relief and of the different forms of erosional surfaces in Iowa.

The movement of materials by water is down grade. The rill on the hillside, the sheet wash during a heavy rain, the tributary stream and the river all carry materials to lower and lower levels.

Some of the material, the load, is rolled along the stream bed; some is carried in suspension by the eddying currents, and some mineral substances are dissolved by the water. If running water secures its load by prying detritus loose, part of its energy is used, and hence it cannot transport as much material as if a capacity load of loose material were available without consumption of energy. The conditions for maximum erosion in glacial material in a minimum time include the existence of steep slopes, a large volume of water, and the presence of abundant fine detritus. The absence of these conditions results in minimum erosion.

If within a region conditions favorable for erosion prevail and the time of erosion is sufficiently long a topography is developed which may not at all resemble the former topography of the area; if the conditions for erosion are unfavorable little change in topography results even in a great length of time.

The rapidity with which streams cut their valleys in a given material depends chiefly upon the volume of flow, the amount of available material of proper size for transportation—the potential load—and the velocity or rate of flow. When the slope of the valley has been reduced to the condition where the stream can just carry its total load over its bed without essential addition or subtraction of material it is at grade or graded.

When the load in a graded stream is increased or the volume of the stream is decreased the stream may be unable to carry the load, and hence leaves part of it on its bed, thus aggrading its channel. When the load is reduced or the stream volume increased the stream again sets to work to acquire its capacity load and begins to cut into its bed, thereby degrading its channel. Streams in the process of building up their channels are known as aggrading streams, and those lowering their channels, degrading streams.

There are three major areas in Iowa in which the present surfaces are the result chiefly of erosion by running water; two areas in which erosional surfaces have been mantled by drift to produce drift mantled erosional topographies, and three areas in which erosional surfaces have been mantled by loess to produce loess mantled erosional topographies. The main features of unmodified erosional topographies, of drift mantled erosional topographies, and of loess mantled erosional topographies will be described.

AREAS OF EROSIONAL TOPOGRAPHIES IN IOWA

There are three areas in Iowa in which the present surfaces are the result chiefly of erosion by running water. The largest of these areas is in southern Iowa; a small area is in the northeast corner of the state, and the third area, also small, is in the northwestern corner of Iowa. All are thinly mantled with loess.

Erosional Topography in Southern Iowa.—The area in southern Iowa includes most of the southern three tiers of counties and the southern part of some of the fourth tier of counties north of the southern boundary of the state. The western edge of this area merges into the loess mantled topography along the Missouri valley. The eastern extension reaches Mississippi river and the southern extension is in Missouri. Except where defined by state boundaries the area under consideration merges into areas with different topographic expressions. However, a somewhat distinctive margin is seen along middle Raccoon river through Guthrie, Dallas, and Polk counties, where the stream follows closely the border of the Wisconsin drift. Elsewhere the line which has been drawn might with equal fitness have been drawn anywhere within an area from one to several miles in width. While this is true each adjacent area possesses modifications which cannot well be included in the descriptions of the typical features of southern Iowa.

The erosional area in southern Iowa is an irregular rectangle about 210 miles long east and west, and about 70 miles wide. The Mississippi-Missouri divide and Des Moines river cross the region diagonally from northwest to southeast and divide the area into three unequal parts. The least dissected topography is in the eastern part of the region. Here flat-topped divides are remnants of a former extensive glacial drift plain which had a gentle slope to the eastward from the Mississippi-Missouri divide to Mississippi river. Within this area a large part of Washington county and parts of adjacent counties show only slight erosional modification of the original plain. With the exception of the areas close to the main drainage lines, the valleys are broad, open, and shallow; between these valleys the uplands are flat "tabular divides" and are drained along broad shallow depressions which are the headward extensions of the valleys. The broad open valleys, the very gentle slopes, and the completeness of the drainage indicate a long time of erosion, during which there has been developed almost perfect adjustment of the streams at grade.

When valleys are followed downward from the broad shallow depressions in the uplands they are seen to merge into broad shallow sags. Thence the valleys are deeper, the walls higher, and the slopes steeper. Yet the tops widen out to maintain the widely flaring profile. Still farther down the valleys, the broad slopes are broken by the development of more steeply walled inner valleys, which carry streams clearly not at grade. The walls of these inner valleys are gullied, the slopes are relatively steep, but in their upper parts the gentle slopes of the earlier profiles are retained. In the longer valleys the inner valleys merge in their lower courses with more open valleys in which the streams wind back and forth across meander-scarred flood-plains. The walls grade from sharp slopes into slopes which are more gentle. The side gullies widen as do the main valleys.

The valley profiles indicate that all parts of the valley are not of the same age. The streams are cutting headward slowly but effectively. In a short distance only along the course of the valley is there major down-cutting. Above these portions the streams are essentially at grade; below the sections of down-cutting the streams by lateral planation have developed flood-plains, slopes have been reduced, and the streams are meandering streams. Although the streams have accomplished much they have important tasks yet to do.

It has long been observed that the slopes on the north sides of east-west valleys are less steep than those on the south sides, with a tendency for the streams to flow close to the south wall. Many of the valleys of southern Iowa exhibit this tendency. In explanation, it has been suggested that the greater heat from the direct rays of the sun on the south facing slopes causes alternate freezing and thawing in winter and greater daily changes in summer. As a result, more material is weathered and prepared for transportation than on the protected slopes. During rains and times of thawing the loose material is removed, thus reducing the angle on the north side of the valley wall to a greater extent than on the side where weathering is less effective. The north facing slopes also are rather uniformly protected by trees which find the conditions congenial because of freedom from droughts such as occur on the sun-dried south facing slopes.

The most impressive single topographic feature of southern Iowa is the Des Moines river valley. This valley has been described in considerable detail by Lees,[1] who presents evidence in support of the judgment that its history began in Aftonian time. The flood-plain ranges from a fraction of a mile to more than a mile in width; the valley walls rise in gentle slopes for more than two miles on either side, making the width of the valley in places six miles or more. The side valleys where they join the main valley have characteristics similar to the main valley, but these valleys narrow abruptly in the upland areas.

The Des Moines valley has a mature topography and the river is at grade, hence there is now no down-cutting in the valley floor. The flood-plain is being widened by lateral planation and the river is removing the detritus furnished by tributary streams.

In southern Iowa west of Des Moines valley there is the same general type of topography as east of the valley, but west of the valley the upland areas, the "tabular divides", are smaller than they are to the east of the Des Moines valley. The drainage lines have encroached upon the upland areas until they are now only remnants of the original plain. Some of these remnants might be described as "shoe string divides". The accompanying figure 7 shows the size and shape of some of these upland areas as taken from topographic maps. Still farther west the upland areas are even more reduced, they are indeed only remnants of the plain which once was the distinctive feature of the region. However, the even skyline, the accordant upland levels, remnants of a gumbotil plain, and other features make it possible to reconstruct without difficulty the original widespread drift surface.

The Mississippi-Missouri divide, which includes high areas in Audubon, Guthrie, Madison, Union, Clarke, Decatur, and Wayne counties, is not a distinct topographic feature, but is rather a high plain which has been maturely dissected by the headward

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[1] Lees, James H., Physical Features and Geologic History of Des Moines Valley: Iowa Geol. Survey, Ann. Rept. 1914, Vol. XXV, pp. 429-615.

erosion of streams. The streams to the west of the divide flow to Missouri river, those to the east flow to the Mississippi. West of this divide the divides of the interstream areas also are upland remnants. They are elongated to the southwest and parallel the drainage. The topography which results is known as

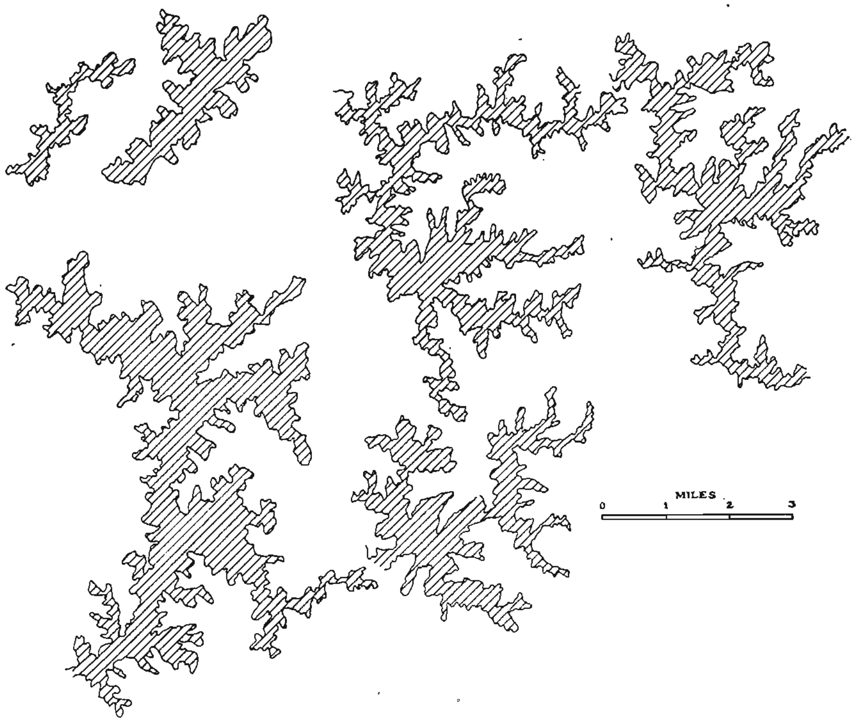

FIG. 7.—Sketch showing shapes and sizes of some of the level upland divide areas in southern Iowa.

"washboard topography" and is well exhibited in Decatur and Ringgold counties. The relief is somewhat greater here than in other parts of southern Iowa. Wherever the streams are close together, erosion has brought nearly all the surfaces below the upland levels, and the divides have knobs and saddles with only the knobs reaching the height of the former surface. In the lower stream areas the valleys are broad—many times the width of the streams—and flat-bottomed. In places the slopes of the valleys are rather steep; in other places the slopes are gentle. Convex curves of the interstream areas are a distinct feature; the valley floors are the flat areas of the present surface. In places, there is relief of nearly 200 feet within comparatively small areas. In such places the topography is rugged.

The erosional area of southern Iowa has in general a progressively older topography from its eastern part to its western border. The plain which was formed at the time of retreat of the Kansan ice sheet has been cut away only along the lower stream courses in the eastern part of the area, whereas farther westward the areas of upland are fewer and smaller, and the valley slopes occupy an increasing proportion of the area. These valley

FIG. 8.—Photograph showing the broad bottom lands and long slopes along Nodaway river near Hepburn, Page county, Iowa.

slopes in turn merge into valley flats. In the eastern part of the area the Kansan drift is covered by the younger Illinoian drift, but the character of the Illinoian surface is so much like that of the Kansan that the above description is applicable to both.

The maximum erosion in the southern Iowa area is in and adjacent to southern Taylor county, where the few uplands are rounded divides rather than "tabular divides" and where the accordant upland levels are not the striking feature that they are in the eastern part of the area. In the eastern part the prominent level surfaces are the uplands, in the western part they are the bottomlands such as are shown in figure 8.

Only very locally in southern Iowa do the indurated rocks influence the valley forms. Drift was deposited thickly over this part of Iowa by both the Nebraskan and the Kansan ice sheets, and in the eastern part by the Illinoian ice in addition. The drift has been by far the most important factor in the development by erosion of the curving profiles and rolling topography of southern Iowa.

Erosional Topography in Northeastern Iowa.—Typical erosional topography prevails in northeastern Iowa along the northern boundary of the state for about 30 miles from the northeast corner, and south along Mississippi river as far as Bellevue, a distance of about 90 miles. The western margin of this area

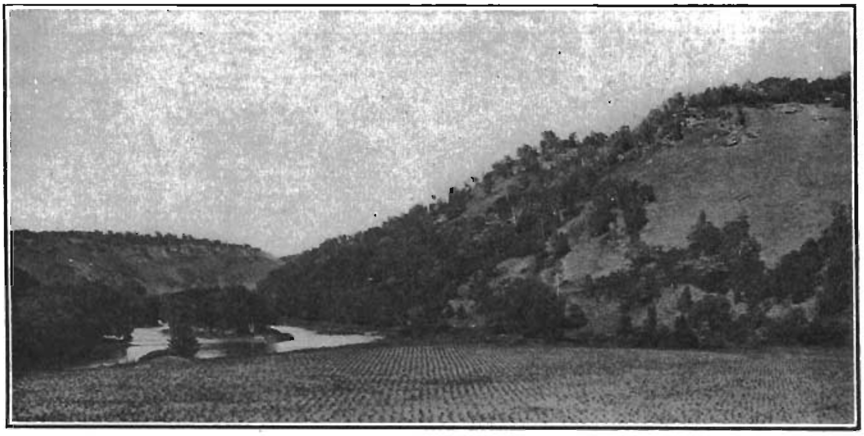

FIG. 9.—Erosional topography in indurated rocks, along Upper Iowa (Oneota) river near mouth of Bear creek, Allamakee county.

is fairly definite but the area is not sharply separated from the adjoining region. The area is in shape an elongated triangle with the apex to the south.

The erosional forms in this area differ from those of southern Iowa, for they have been developed almost entirely in indurated rocks, as shown in figure 9.

Northeast Iowa is related very closely to the Driftless Area, an unglaciated area more than 6,000 square miles in extent in Minnesota, Wisconsin, and Illinois. It is entirely surrounded by glaciated territory. Iowa is not included in the driftless region as patches of till are so distributed within northeastern Iowa that there is no doubt that an ice sheet advanced from the northwest into this area as far, at least in most places, as the gorge of Mississippi river.

Several of the large streams tributary to the Mississippi cross northeastern Iowa and their valleys are at grade, hence the maximum relief of the surface under present conditions has been attained. This relief is about 400 feet locally and as much as 600 feet within distances of a few miles. The uniform rise of the steep slopes is broken in many places by cliffs of resistant formations. Chief of these are the Oneota dolomite, the Platteville limestone, the Galena dolomite, and the Niagaran dolomite. Where shales are at the surface the area has rolling dome and saddle topography indicative of maturity in stream dissection, as shown in figure 10.

FIG. 10.—Mature dissection and slopes in weak rock (Maquoketa shale) west of Dubuque. View from summit of Table Mound.

As one travels through the northeast part of Iowa he is strongly impressed by the even sky-line as seen from the summits of the divides. Some of the upland areas are broad with a very gently rolling surface. Here and there rising steeply above the even sky-line are knobs and secondary ridges whose summits also reach uniform elevations. The two levels attained by different parts of the divides are strikingly consistent, and when studied throughout the driftless area they are interpreted to be remnants of two old erosion surfaces. The upper level, called the Dodgeville peneplain, is between 1200 and 1300 feet above sea level. In the vicinity of Waukon, Church, Elon, and Rossville in Allamakee county it consists of remnants in branching divides with flat tops. The much more extensive lower plain slopes from an elevation of about 1100 feet at the Minnesota line to an elevation of about 900 feet at Dubuque. The summits of many of the divides within eight to ten miles of Mississippi river are parts of this plain, which is known as the Lancaster peneplain.

The record of erosion of northeastern Iowa is not the record of the work of streams after only one adjustment of level between land and sea, but of work following adjustments at four different levels at least. The oldest level, the level of the Dodgeville peneplain, has a relief of about 200 feet. Nearly 200 feet below the accordant plain levels of this peneplain are the levels of the Lancaster peneplain with a relief of about 100 feet. The present streams are in valleys about 400 feet below the Lancaster peneplain in the northern part of the area and somewhat less in the southern part, and these streams flow on valley fills which carry the waters as much as 200 feet above the rock floors of the valleys.

An old drift in this area appears to be limited in distribution[2] to surfaces which are near the level of the Lancaster peneplain or at levels higher than this peneplain. This drift has been found in place nowhere in Iowa much below the Lancaster peneplain.

The topography represented by the three erosion levels in northeastern Iowa is unique for Iowa. Nowhere else in the state is there similar topography. The flat divides in some places are sufficiently extensive to be called "prairies". On the edges of these prairies there are slopes or cliffs which form the valley walls, as along Mineral creek, figure 11. The sharp angled courses of the streams follow closely the irregularities of the valley walls and into the walls of the valleys, gashes and gullies have been cut. Some of these have small permanent streams, while others have intermittent streams.

The jutting prominences where side valleys enter main valleys at low angles and the rounded headlands where tributary courses enter larger valleys at high angles are conspicuous features of the topography of northeastern Iowa. The re-entrants reach well back toward the divides, leaving, in most places, only narrow ramifying strips to represent the peneplain at the top of the interstream areas.

2 Williams, A. J., unpublished manuscript. Library, State University of Iowa.

The general features of the region of northeastern Iowa are impressive, occurring as they do in this state in the midst of surrounding glaciated territory with comparatively gentle relief. The accordant upland levels, the presence of a drainage so young as to have only sharp valleys with gully and gulch crenulated valley walls, cliffs or steep slopes depending upon the relative resistances of the rocks to erosion, and the reliefs of 400 feet to 600 feet are so different from the features of other parts

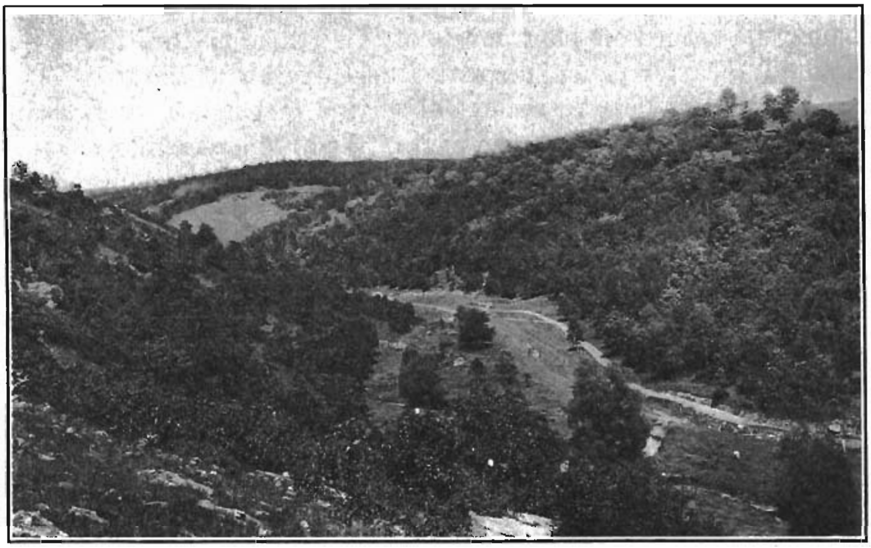

FIG. 11.—Steep-walled valley of Mineral creek, Allamakee county.

of Iowa that they create more than casual interest in one who visits this picturesque region.

The cultural development of northeastern Iowa has been profoundly affected by the rugged topography and the absence of natural accessible travel routes. This is shown clearly by comparing the road patterns of two townships of this area with two townships in the southern Iowa area and with two townships in northwestern Iowa, as in figure 12. These patterns illustrate the effect of the necessity of abandoning the rectangular road system in northeastern Iowa on account of the irregularities of topography.

Erosional Topography in Northwestern Iowa.—The portion of the state included in the northwestern Iowa erosional area

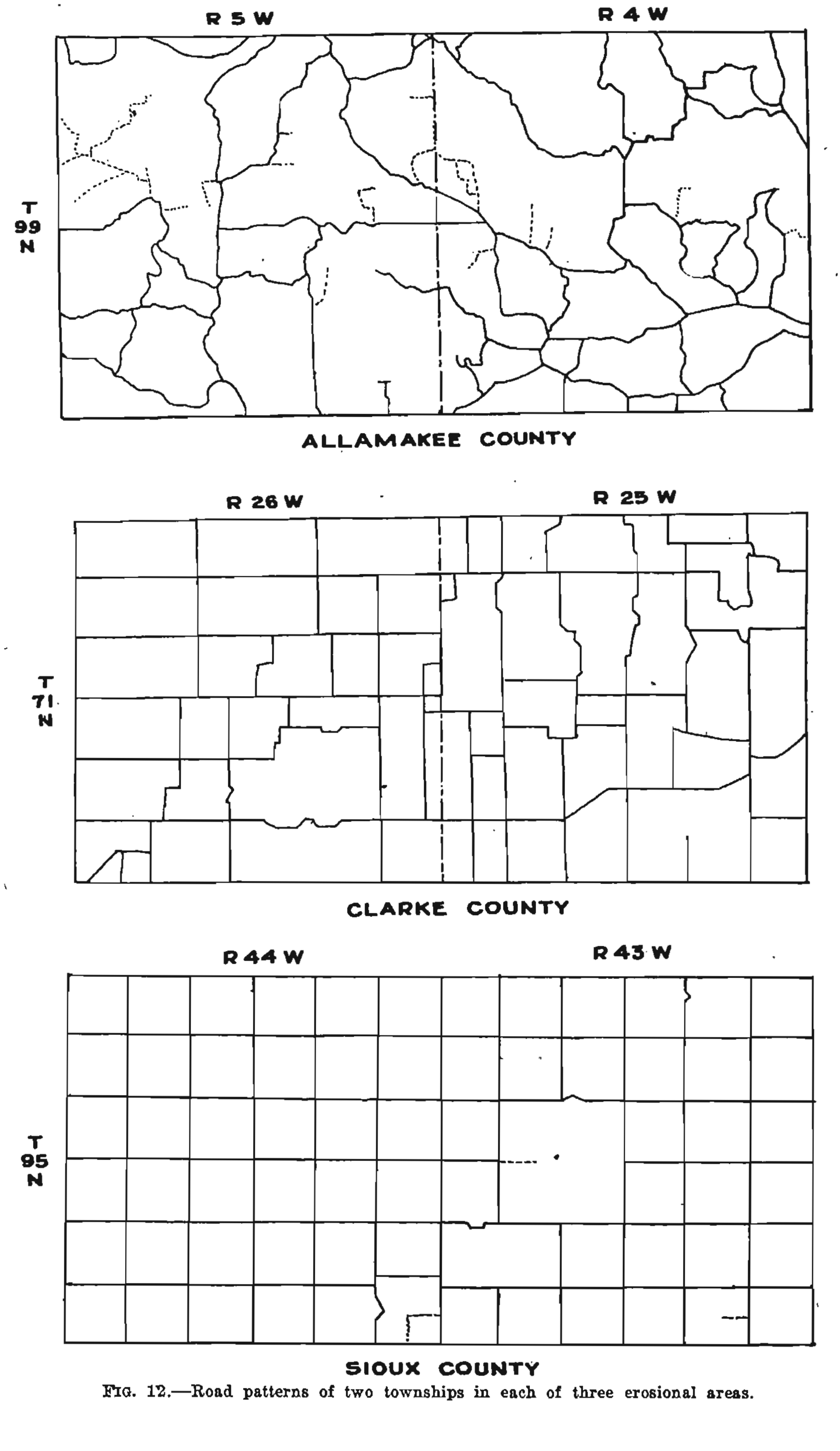

FIG. 12.—Road patterns of two townships in each of three erosional areas.

lies in parts of Lyon, Sioux, O'Brien, Plymouth, and Cherokee counties. The surrounding areas, although not very different in topography from this area, are sufficiently distinct to merit separate description.

The typical feature in this part of northwestern Iowa is the rolling topography with gentle slopes such as characterize a region which has been long subjected to erosional processes. The maximum local relief of the area is 200 feet. The surface is undulatory, with broad even slopes extending down to the bottoms of the valleys. Floods overflow the areas adjacent to the normal creek channels, but the run-off is rapid. Only the larger streams have flat valley bottoms of appreciable size, and these, while they are locally well developed, are not distinctive in relation to the area as a whole. The absence of precipitous slopes, marked local relief and large flat uplands, and the presence of complete drainage indicate that the agents of erosion have been very effective in the production of the present surface. If this area was at one time a plain, as in southern Iowa, this plain has been destroyed by erosion. However, the broadly complex hills rise to an approximate plane which slopes slightly to the south and west. In this area there are few exposures of indurated rocks.

Resumé.—The three erosional areas which have been described have differing topographies which are the result of the same processes. The differences in the topographies are due primarily to differences in types of material in which the agents of erosion have worked, to differences in the characters of the original surfaces, and to differences in the lengths of time to which the areas have been subjected to erosion under present adjustments.

The oldest surface represented is the Dodgeville peneplain in northeastern Iowa: this surface is pre-Pleistocene in age. The Lancaster peneplain surface is thought to be pre-Pleistocene also. On this latter surface but nowhere far below it there is drift believed to be of Nebraskan age.

The greater part of the relief in northeastern Iowa which is below the level of the Lancaster peneplain is thought to have been carved since the retreat of the Nebraskan ice sheet, the drift of which is now present only in isolated patches on the surface on which it was deposited. This post-Nebraskan erosion which resulted in the development of a relief in indurated rocks of 500 to 600 feet below the Lancaster plain must have involved a very long time—but it was essentially completed before the coming of the Kansan ice.

The topographies of southern and of northwestern Iowa were developed by the erosion of drift plains. Southern Iowa shows the effect of streams working at different elevations above grade level. The erosional area in northwestern Iowa now has only gentle slopes above the grade of its present streams.

DRIFT MANTLED EROSIONAL TOPOGRAPHY

There are two areas in Iowa which, after a mature erosional topography had been developed, were modified by the deposition of a mantle of drift over the erosional surfaces. The mantle is in places thick enough to produce distinctly constructional features. Although these areas are "not generally dissected by sharp cut, eroded valleys, there are yet present nearly everywhere the main features of maturely branching stream erosion systems. The valleys divide and subdivide in dendritic fashion, and their branches reach most parts of the area. Even the more nearly flat and less dissected parts show this drainage pattern."[3] The two areas to be described will be designated the eastern Iowan area and the western Iowan area.

The Eastern Iowan Area of Drift Mantled Erosional Topography.—The eastern Iowan area occupies the greater part of the northeastern quarter of the state. The area includes all or parts of twenty-five counties as is shown in figure 6. It is roughly quadrilateral in shape.

The boundaries of the eastern drift mantled area are fairly definite. Most of the west line lies along the morainal margins of the Wisconsin drift, the east, south and southwest sides are bordered by thick loess and sand deposits, and the Minnesota-Iowa state line marks the north edge. The drift mantle of this area is Iowan drift; it lies on an eroded Kansan drift surface.

From a topographic standpoint this area is more typically "gently rolling" than any other part of the state, and there is no

3 Alden, Wm. C., and Leighton, M. M., The Iowan Drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, Ann. Rept., 1915, Vol. XXVI, p. 61.

distinct topographic datum plane to which the relief can be related as in southern Iowa. The river valleys are in most places fairly broad in relation to the streams in them, and instead of these broad valleys having wide flood-plains many of them have concave profiles. Some writers have stated that the streams flow in "sags" which extend for miles along the stream courses, the sags being best explained as partly filled broad valleys. The flood-plains in some places at least are not built of alluvial materials, but are drift flats appearing now probably much as they did when the ice-sheet left them.

The broad sags are bordered by lines of hills, in some places with very gentle slopes, and in other places with steep slopes. Nowhere is the relief locally great. Although here and there the hills look somewhat formidable from a distance, it is seen upon close approach that the slopes are gentle. As a rule, the relief is less than 100 feet; but even such relief is sufficient to give somewhat commanding elevations in the landscapes. The divides are usually undifferentiated either by prominence or continuity from the hills which lie along the stream valleys.

In parts of this drift mantled area the relief is very slight, and the surface for mile after mile appears to the eye to be almost level. All parts are drained, however; no lakes exist, but small ponds are formed in depressions during heavy or prolonged rainfall, and formerly extensive areas were boggy during wet seasons. The slight relief which is characteristic of these flat areas cannot be explained satisfactorily as being the result of erosional agencies alone, but rather as having been made by the deposition of material distributed irregularly over broad tabular divides remaining on an erosional surface. The broadly concave valleys, the inconspicuous divides, and the swells on drained level stretches indicate a depositional modification of a normal erosional surface. In accord with this interpretation is the presence of numerous immense boulders and many boulders of less size which are not distributed in relation to major drainage lines, but which occur with little relation to the topography. One of these boulder fields is shown in figure 13.

The drift mantled area has within it many outcrops of indurated rocks. These are most prevalent along the drainage lines; in places they are the walls of gorges, and in other places they outcrop only in the beds of streams. To a very limited extent only have these indurated rocks been effective in determining the development of the present topography. They are spectacular features, but outcrops are restricted, and hence they have no important areal or topographic significance.[4]

The Northwestern Iowan Area of Drift Mantled Erosional Topography.—The northwestern Iowan area of drift mantled erosional topography includes nine counties; it is about twice as long as it is wide, with the long axis extending a little east of

FIG. 13.—Boulder field on the Iowan plain in Buchanan county.

south from the Minnesota line, as shown in figure 6. The east boundary is strongly bowed eastward following the edge of the Wisconsin drift, whereas the west boundary is bowed slightly to the west. The drift in this area, as in the eastern drift mantled erosional area, is Iowan drift lying on an eroded Kansan drift surface.

The northwestern area differs from the northeastern area in that the drift mantle in the northwestern area was deposited on a surface which had been reduced by erosion not only to a mature stage but to a stage well advanced toward old age. Such a surface has less conspicuous relief than a mature erosional surface and when covered by a mantle the new surface is likely to obscure more of the characteristics of the underlying erosional surface than in a region where the drift mantle is deposited on a mature erosional topography. The more the underlying erosional features are obscured the more apparent are the effects of the

[4] Alden, Wm. C., and Leighton, M. M., The Iowan Drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, Ann. Rept., 1915, Vol. XXVI, p. 71.

mantle. In the northwestern Iowan area the valleys and their tributaries do not have the distinctive dendritic drainage features characteristic of topographies due to erosion only. In places the valley walls have been sharpened or smoothed, in other places spurs due to deposition extend into the valleys, and in places there is morainal topography.

LOESS MANTLED EROSIONAL TOPOGRAPHY

Over much of the surface of Iowa there is a mantle of yellow, silty clay called loess. This loess mantle differs in thickness locally and regionally. Only those areas in which the loess mantle is sufficiently thick to modify the underlying erosional topography are here considered as areas with loess mantled erosional topographies.

Loess may influence an erosional topography in at least three ways: it may increase the relief by the deposition of more loess on the divide areas than in the valleys; it may reduce the relief by the deposition of more loess in the valleys than on the divide areas; and the distribution of the loess may be such that the amount of the relief is not distinctly changed, and yet by altering the angles of slope and by building structures on the hillsides, a modified topography may be developed. All these types of modification are found in the state.

The boundaries of the loess mantled areas are necessarily somewhat arbitrarily drawn. It is more difficult to decide upon a proper boundary where the loess thins gradually than where it thins somewhat abruptly.

Three areas in the state will be considered as having loess mantled erosional topographies. One area is in the western part of the state, a second area is in the northeast part of the state, and the third area extends from near the middle of the state to near the eastern border, as is shown in figure 6. These three areas are designated, for convenience, the Crawford area, the Jackson area, and the Cedar area, respectively.

The Crawford Area.—Crawford county gives the name to this broad bowshaped area which parallels in general Missouri river. In its middle part the area has a width of about 40 miles; from here it narrows both north and south to the borders of the state. Parts of 19 counties are included in the area. There are gradations on the east and west into topographies which have not been included in the Crawford area except where Sioux river is the boundary on the west, and in Ida and Carroll counties where the Iowan and Wisconsin drifts form the boundary of the Crawford area.

The prevailing position of the loess in the Crawford area is on the tops of hills and on the upper parts of the slopes. Thinner loess extends into and across the valleys, giving the appearance of loess built topography, but numerous road cuts and some exposures along the valleys show clearly that the cores of the hills are drift and that the loess in the valley bottoms is thin. On the higher slopes the loess is from 10 to 30 feet or more in thickness, whereas on the lower slopes the loess is in most places less than 10 feet, locally only three or four feet in thickness. The abundant loess in the upper slopes in many places has a definite relation to the drift core. The crest of the hill, due to loess deposition, has migrated to the eastward with the loess asymmetrically distributed over the drift; it is thicker on the east side than it is on the west side. This is a normal relationship in this region; the loess, a wind-blown material, was carried from the west, and hence the windward slopes have had deposited upon them less of the loess than was deposited on the leeward slopes. Thus coincident with increase in relief by loess deposition the slopes were modified. The eastern slopes particularly show the effect of the migration of the crests of the hills without equivalent shifts of the valley bottoms. Western slopes may show slight modification or if the increase of relief by loess deposition is relatively great when compared with the drift relief the westward slopes may be appreciably steepened. Figure 14 shows this loess mantled type of surface in Crawford county. The hill and valley modifications are not everywhere uniform in character nor are they of the same kind. The western part of the Crawford area has more loess, and hence is more modified than the eastern part. This is as would be expected since it is nearer to the chief source of loess supply, which is the Missouri valley.

The somewhat heavy mantle of loess over the Crawford area is believed to have been deposited chiefly during the Peorian interglacial epoch. There is beneath this younger loess an older loess and a series of silts and sands which lie unconformably upon the eroded surface of the Kansan gumbotil plain, and which contribute in a minor way to the topographic development of the area. These older deposits, which in part, at least, are correlated with those known to be younger than the Illinoian and older than the Iowan, constitute the Loveland loess and associated silts and sands. Since the deposition of the mantling loess much shifting of the material has occurred. Some of it has been transferred by the wind and some of it has been washed

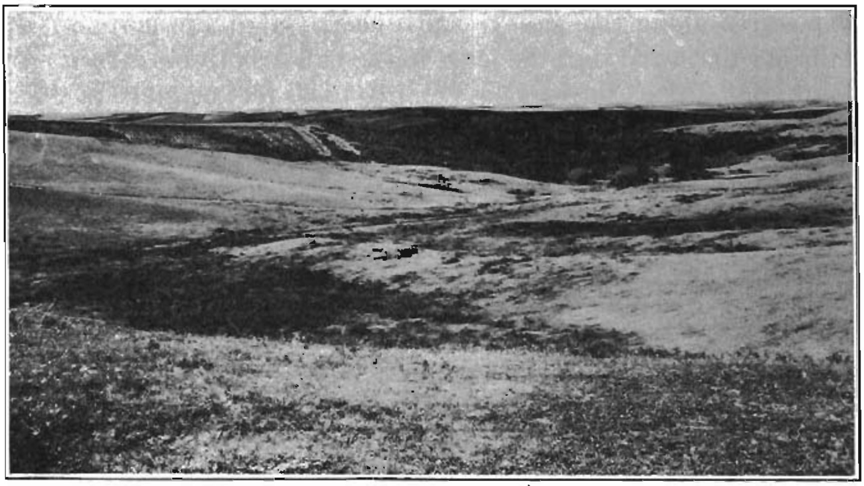

FIG. 14.—View in central Crawford county showing type of erosional topography which is loess mantled.

into stream valleys. Some of the smaller streams have been aggraded with loess and yet aggradation has not been very great as the flood-plains are still narrow and are flanked by abrupt slopes at the bases of the loess covered hills.

Different parts of the Crawford area differ in relief, in drainage development, and in proximity to large stream courses. However, they are remarkably consistent in having the loess surfaces characterized by asymmetric hills and valleys and in having limited outcrops of drift.

The Cedar and Jackson Areas.—The typical loess mantled erosional areas of northeastern Iowa are found in parts of Cedar and Jackson counties. These areas lie respectively at the south and east margins of the Iowan drift, the boundaries of which are sinuous and along which the loess thickens abruptly. Where the boundaries of the loess mantled areas are over Kansan drift the loess thins gradually and hence the lines of separation of the topographies are not definite.

The reliefs of the Cedar and the Jackson areas differ somewhat. The maximum relief of the Jackson area is about 400 feet, whereas the relief of the Cedar area is only about half as much. The proximity of the Jackson area to Mississippi river, and the underlying indurated rocks, account for the greater re-

FIG. 15.—Loess dunes on valley slopes in Scott county.

lief in this area. The indurated rocks in the Cedar area have had but little effect upon the topography.

The prevailing features of the Cedar and Jackson areas are loess-built structures on the hill slopes and thick loess deposits bordering the erosion carved valleys. The modifications of the erosion slopes take the form of rolling hills—dunelike accumulations of loess and sand, as shown in figure 15. The total relief of the surface is increased somewhat by the presence of the loess, but the chief result has been the multiplying of slopes together with the steepening of the slopes along the river valleys. On the uplands or divides the loess is in most places thin, perhaps not more than ten feet thick. These divide areas are gently rolling, conforming to the major slopes of the underlying erosion surface, but have their own distinctive topographic expression as seen in the variations in the convexity of the different parts of the slope and in the minor surface irregularities. A modified valley wall is shown in figure 16.

Near the main stream courses the loess is thicker than on the divides, in many places reaching a thickness of thirty or forty feet or even more. Here the underlying erosional drift topography has been distinctly modified. Slopes east of the valleys have undergone greatest modification, indicating the effect of the prevailing westerly winds. The crests of the hills along the

FIG. 16.—Thickly loess-covered valley walls in Johnson county, showing multiplied slopes formed on the loess.

valleys are capped asymmetrically by loess—thickest on the eastern leeward slopes. The hill slopes are broken into a series of undulating convex and concave curves. The shoulders of the hills are rounded by loess with accompanying steepening of the lower slopes. Deforestation and cultivation have in many places caused gullying to proceed rapidly, showing that the loess built slopes are not adjusted to present drainage.

The slope modifications which have been described are proportionally less pronounced in the Jackson area than in the Cedar area, owing chiefly to the greater erosional relief in the Jackson area.

Depositional Topographies in Iowa

DRIFT DEPOSITIONAL TOPOGRAPHY

The area of the Wisconsin drift is the only area of distinctly drift depositional topography in the state. The boundaries of this area are fairly distinct, extending from the Minnesota line southward to Des Moines to form a lobe, the axis of which from the state line is directed somewhat east of south. The area includes all or parts of twenty-nine counties.

The surface of this area is now nearly as it was when the Wisconsin ice sheet retreated from it. Around the borders of the drift lobe there are in places strong terminal moraines—piles of glacial débris marking the farthest advance of the ice. Between the stretches of well developed terminal moraines there are less prominent yet conspicuous slopes above the levels of the drifts outside the lobe. Within the moraines the surface alternates between wide stretches of ground moraine and recessional moraines which mark stages of halting during the ice retreat.

Des Moines river and its tributaries drain the western two-thirds of the area; the head waters of Skunk, Iowa, and Cedar rivers drain the eastern one-third. These streams and their

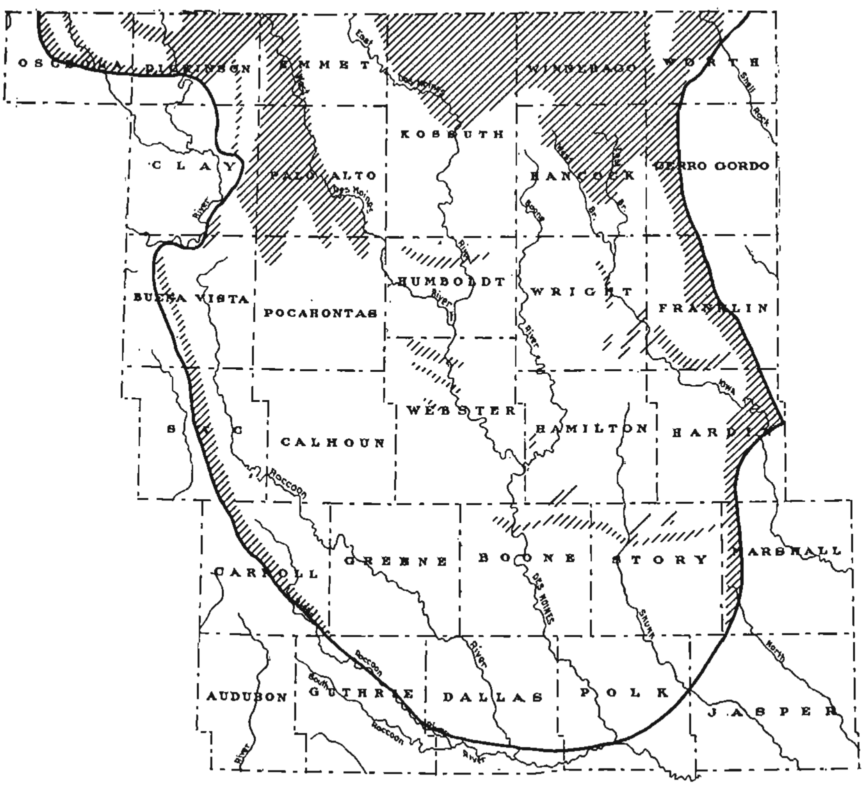

FIG. 17.—Sketch map of the Wisconsin drift lobe in Iowa showing hilly morainal areas. (Compiled from sources published in volumes of the Iowa Geological Survey.)

tributaries are in youth, and hence drain only a comparatively small part of the area. Between the heads of the drainage lines are broad stretches of undrained lands. Numerous lakes, ponds, and marshes are striking features of the surface. Many artificial drainage projects have been completed in recent years, and as a result much of the formerly wet untillable land is now under cultivation.

Within this area of Wisconsin drift two types of surfaces may be recognized: the terminal and recessional moraine type and the ground moraine type. The former type of surface is characterized by marked relief; the latter by slight or gently undulatory relief. The accompanying sketch, figure 17, shows the major morainal areas which have been mapped and the areas of ground moraine.

The morainal hills as a rule rise above the level of the ground moraine plain and have no definite relations to drainage lines. They are constructional surface features due to deposition. The piles of débris which the glacial ice deposited at its margin have a "knob and kettle" topography, with the knobs differing in size and height, irregularly spaced, and limited in distribution. The kettle shaped depressions are the low spots among the knobs, as in figure 18. They differ in size and depth and many of them contain pond water. The kettles are likewise limited in

FIG. 18.—Morainic knob and kettle in Dickinson county.

distribution since they are associated with the knobs of the moraines or are depressions adjacent to the moraines.

In some places the morainal areas have rolling hills with slopes of low angles, with crests at different elevations, and with the spaces between the hills presenting no definite arrangement. Such features are in sharp contrast to the features of a topography developed by erosion.

The glacial movement which extended the Wisconsin ice sheet over the land was limited to the distance it could push the ice margin and there maintain it in spite of the factors which were operating to cause it to retreat. Where the melting of the ice just kept pace with the ice advance the débris carried by the glacier was deposited to form marginal moraines. If the halt was long, great piles of detritus developed strong moraines; but if the halt was short or the ice was loaded only lightly then the resulting moraines were small. Because the morainic areas occupy positions once definitely related to the ice sheet it is in the larger features of distribution, extent, and size that some classification of the moraines can be made. For example, one large morainic area near the border of this Wisconsin drift area has been named the Altamont moraine. A smaller series of morainic ridges within the drift area is known as the Gary moraine. Other minor areas of morainic topography are unnamed or have local names.

The ground moraine type of surface is a drift plain. If instead of the glacial margin remaining stationary to pile up knobs and hills the retreat of the ice sheet was relatively uniform, the glacial load was laid down in a well distributed sheet of drift. The surface of course was not smooth although it was approximately level. No drainage lines were established except those carrying water from the melting ice. In the depressions the water gathered to form lakes and ponds, some of which in the course of time were destroyed by having their shallow basins filled with sediment and organic material. Areas of peat and black muck are witness to the number of these former low spots. Their distribution in Wright county is shown on the accompanying sketch map, figure 19, prepared from the soil survey map of the county.

The drift plain, as the level areas are called, is gently undulat-

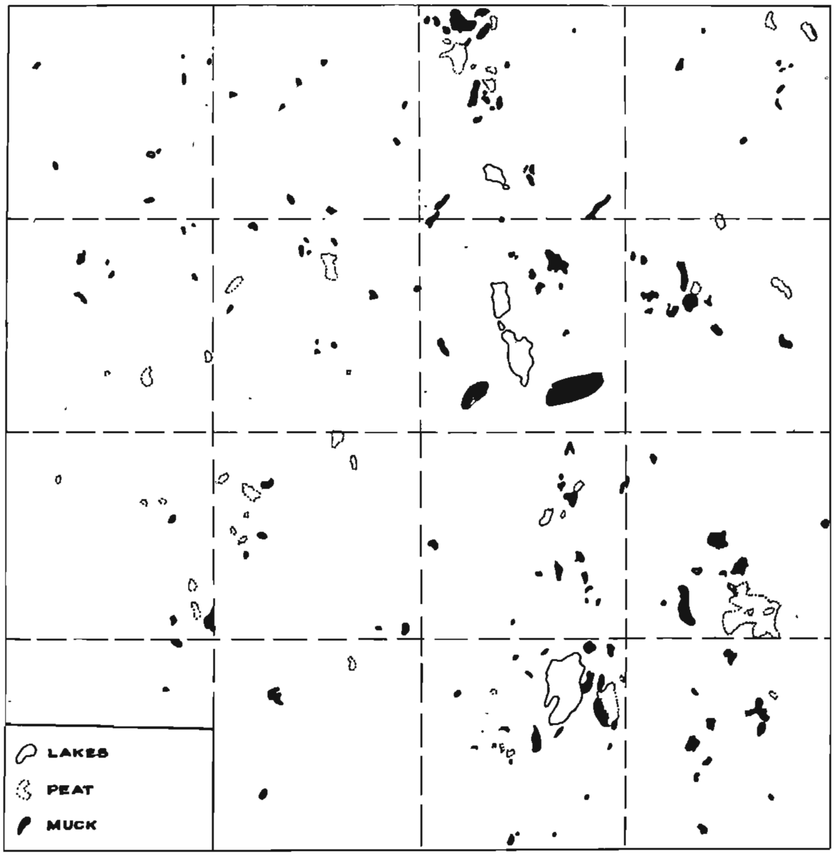

FIG. 19.—Sketch map showing peat, muck and lake areas on the Wisconsin drift plain in Wright county.

ing. Very broad dome-shaped elevations, or elongated low ridges rise slightly above the general level of the plain. In the lower parts of the plain are the lakes, ponds, and marshy areas. Over the area as a whole the divides are discontinuous and the valleys lack the features of valleys with an erosional history.

Whereas the major part of the Wisconsin drift surface is geologically very new, it has in some parts been undergoing effective drainage. The waters which flowed from the melted ice started channels which were easily followed by the runoff from rains. The low areas between these channels soon filled with water and overflowed to the channels. Some open sags carried surface waters as if they were eroded valleys. Only a limited part of the surface water could be retained by the irregularities of the plain, and the rest was forced to seek the low saddles and to open courses in which it established new drainage lines.

The present drainage is in an early stage of stream development and adjustment. Streams such as that shown in figure 20 are common. Only the lower courses of the secondary streams and the larger rivers show valleys due to erosion, and these valleys are steep-sided and narrow, as the Des Moines valley near

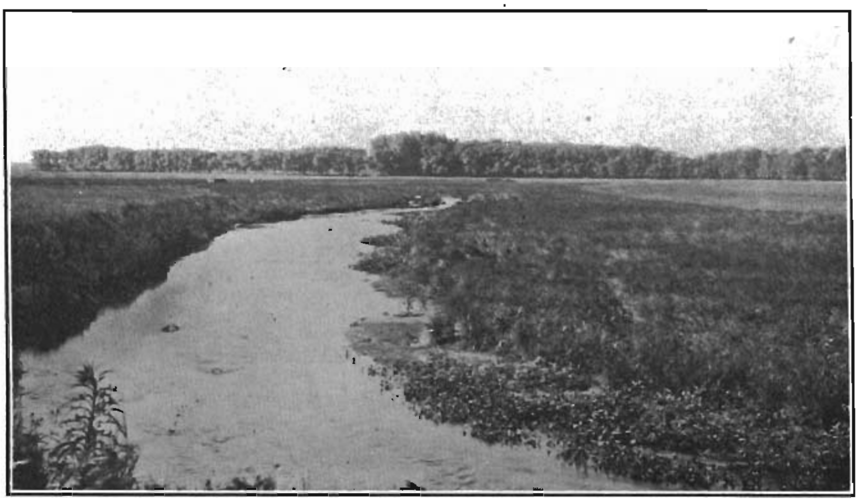

FIG. 20.—A young, unincised stream valley on the Wisconsin drift, Palo Alto county.

Boone, figure 21. A few of the large streams have narrow flood-plains in valleys which may or may not have been developed by the present streams. The gradient of the smaller streams is so slight that ditches have been made in many places to straighten the channels and to bring them with steeper gradients to the larger drainage lines. Even by ditching the fall attained is rarely more than one foot per mile.

The depositional topography of the Wisconsin drift area is in sharp contrast with the old erosional surface of southern Iowa and with the drift mantled surfaces of the Iowan drift areas.

LOESS DEPOSITIONAL TOPOGRAPHY

A narrow strip three to twenty miles in width bordering the flood-plain of Missouri river has loess depositional topography. The area includes parts of Woodbury, Monona, Harrison, Pottawattamie, Mills, and Fremont counties, as shown in figure 6.

To the west is the Missouri flood-plain; to the east is the loess mantled erosional topography of the Crawford area already described.

The area of loess depositional topography has a greater thickness of loess than the area with loess mantled erosional topography. Here, a considerable part of the relief is in loess, as a thickness of 90 feet has been measured above the level of the

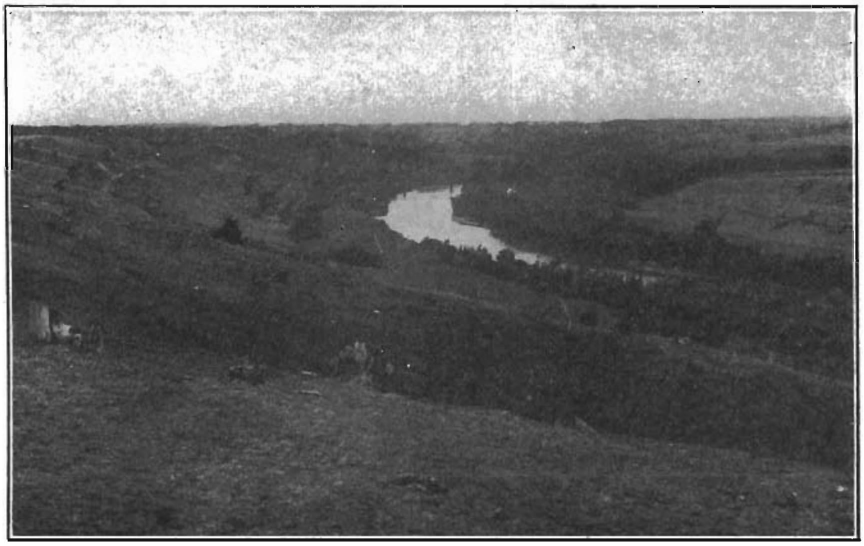

FIG. 21.—Des Moines river valley in Boone county, showing the narrow, steep-sided valley in the Wisconsin drift.

Kansan gumbotil, and thicknesses somewhat greater have been reported by well drillers.

The characteristic features of the thick loess area are the apparent lack of system in the divides, the sharp hills with stepped slopes, and steep valley walls in many places cut by gullies. The relief is more than two hundred feet within distances of a few miles. The area is very rough for a region with such moderate relief.

The interstream areas do not rise by successive elevations to the divides but present a series of irregular, broken, north and south ridges which face the west and are interrupted at each streamway. The prevailing westerly winds which carried the loess chiefly from the Missouri flat have been the controlling factor in the distribution and development of the loess topography.

The hills which separate the waterways are in many places narrow crested and steepsided and have a series of small terraces or steps called "cat-steps" on the more abrupt slopes, as shown in figure 22. These "cat-steps" are the result probably of slipping or faulting along the characteristic vertical joint

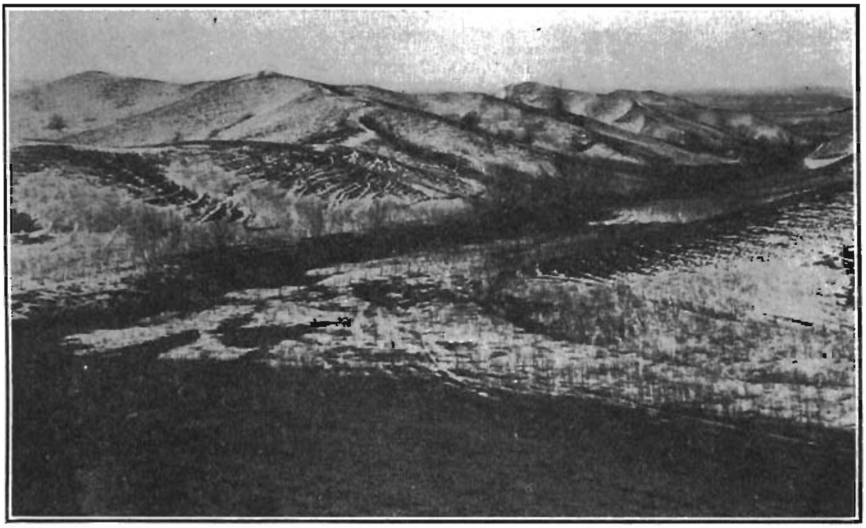

FIG. 22.—Loess hills in Monona county interrupted by a valley. The "cat-steps" or small terraces are well shown by the snow lodged on them.

planes of the loess. The features of loess-built hills are well illustrated in figures 23 and 24.

The thick loess area is well drained. It lies across the lower parts of the westward flowing tributaries of Missouri river, whose heads are beyond the thick loess. The larger streams have relatively broad flood-plains on which the streams meander in short turns. The margins of the valleys are sharply marked by steep slopes and the characteristic hills of the area. These hills readily develop gullies with vertical sides. In no other unconsolidated materials are like features developed to such an extent. Lateral stream erosion is fairly rapid but vertical downcutting of the streams is slow.

LACUSTRINE DEPOSITIONAL TOPOGRAPHY

With the exception of a few small drained lake basins within

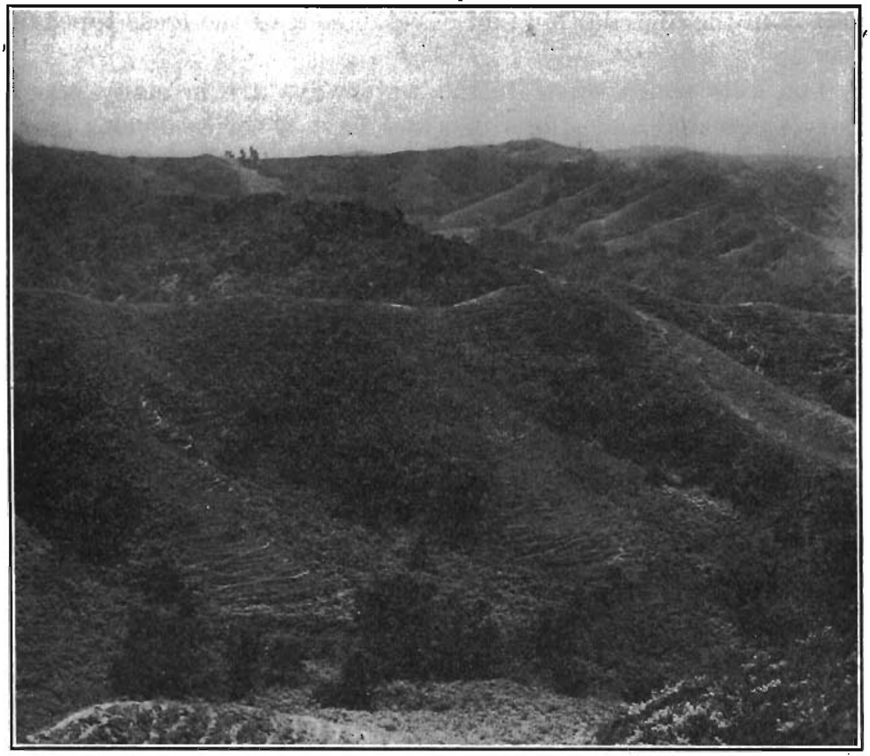

FIG. 23.—Loess hills in Harrison county, showing the "cat-steps" on the slopes.

the Wisconsin drift area there is but one extensive area in Iowa which has typical lake bed topography. This is the old Lake Calvin basin in southeastern Iowa, extending along Iowa and

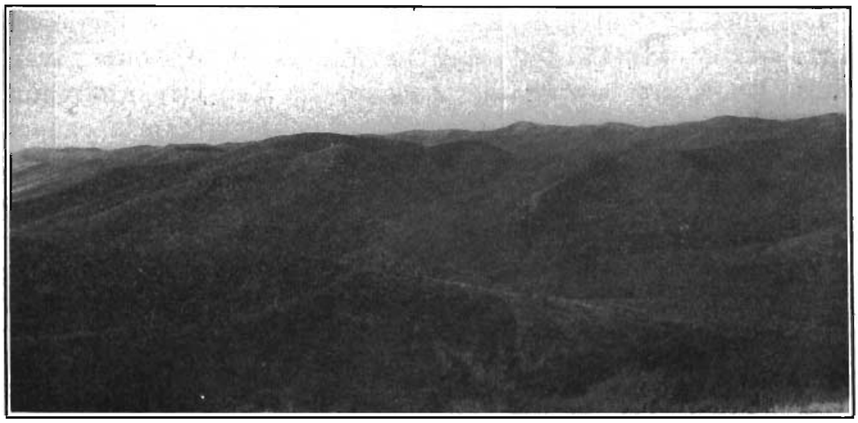

FIG. 24.—General view over loess constructional topography. Talbot Hills, near Sioux City.

Cedar rivers from their juncture up each valley for some twenty-five or thirty miles. The area is broadly V shaped, and includes parts of Johnson, Cedar, Muscatine, Louisa, and Washington counties, as shown in figure 6.

The old lake beaches are in some places still preserved, former islands now stand as hills separated by saddles from the lake shore, and breaks in the former lake shore line are distinctly traceable to streams now active. The materials deposited in the lake basins from incoming waters tended to level up the lake bed and to smooth its floor. When the downcutting of the lake outlet finally drained the lake there was left a broad expanse of level land, with rises to old beaches around its margin and to hills, formerly islands, within the basin. The lake bed after the lake was drained was not covered at once by vegetation; before it became so protected winds piled up some of the surface materials into dunes, so that when vegetation was established the surface was not flat everywhere but was in places hummocky and in places flat as it is today.

ALLUVIAL DEPOSITIONAL TOPOGRAPHY

Along each of the major streams at the border of the state, and also along the valleys of many of the tributary streams within the state, there are flood-plains and terraces, some of which are of considerable extent and some of which are small. The flood-plain areas during times of flood have sediments deposited upon them. During normal stages of the stream these areas are dry. If the stream becomes graded at the level below that at which the flood-plain was built a terrace is formed.

The flat along Missouri river is exceptionally well developed. It is partly drained by the tributaries which cross it. Between these tributaries there are ponds, marshes, or small lakes formed either in relation to the settling of soft sediments or by the damming off by bars of part of the old river bed. The surface relief of flood-plains is low, and their general slopes follow closely the slopes of the streams which form them.

Because flood-plains are limited in elevation to the height to which the waters of the streams rise there are distinct boundaries to these flood-plains on the shoreward side. The slopes above

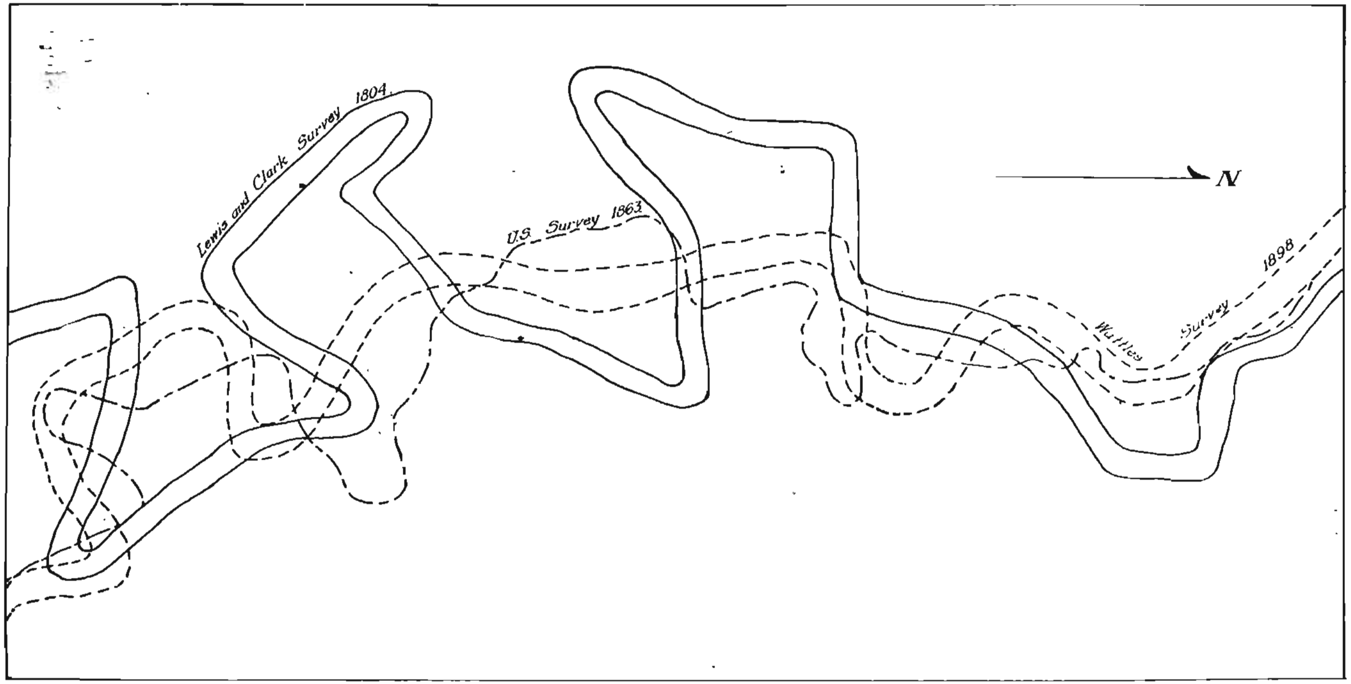

FIG. 25.—Sketch showing the shifting of the Missouri river channel along the boundary of Harrison county, 1804 to 1898. After Shimek, 1910.

them may be low or steep since the flood-plain is essentially independent of bordering areas.

Flood-plain deposits are usually only temporary deposits. The ever-working meanders cut at the outsides of the curves and fill in on the insides, thus changing the channel and shifting the débris ever nearer and nearer to the ocean. The accompanying sketch, figure 25, shows the important shifts which were made along the border of Harrison county by Missouri river between the years 1804 and 1898.

The materials which a stream carries are largely soil materials washed from the surfaces of its drainage basin. It is the composite of many soils, and when deposited on the flood-plain it is wonderfully fertile. The constant shifting of the flood-plain material often influences seriously the flood-plain areas which are under cultivation.

CHAPTER III

HISTORY OF THE INVESTIGATIONS AND CLASSIFICATIONS OF THE PLEISTOCENE DEPOSITS OF IOWA

Introduction*

The history of the investigations and classifications of the pre-Illinoian Pleistocene deposits of Iowa is interwoven intimately with the history of investigations and classifications of all the deposits of Pleistocene age in Iowa and adjacent states of the Mississippi Valley. It seems best therefore not to attempt to treat the pre-Illinoian history independently but rather to include it as a part of the history of investigations and classifications of the whole Pleistocene of the Mississippi Valley. But this history will not be presented here in great detail. Consideration will be given chiefly to those phases of the history which seem to be the most essential to a proper understanding of the development of present-day views regarding the glacial and interglacial deposits of Iowa.

In the year 1837, Louis Agassiz, then living in Switzerland, put forward the theory that there had been continental glaciation in Europe. This somewhat startling interpretation stimulated investigation of mantle rocks both in Europe and in America. Soon in both countries abundant evidence had been found to place Agassiz's view of continental glaciation upon a firm basis. From that time glacial phenomena have been studied by many geologists, and year by year as investigations have continued, more and more of the complex phases of the history of the deposits which were made by glaciers during the Pleistocene or Glacial Period have been unraveled. Nor has finer work been done anywhere than by students of the glacial deposits of the Mississippi Valley. At first it was believed that all the phenomena could be explained in relation to the advance and retreat of a single ice sheet. But soon evidence was found which indicated to some geologists that there had been two ice sheets separated by a long interglacial epoch. This evidence consisted in many places of a forest bed or buried soil separating two tills. For instance, buried soils between tills were described in Illinois as early as 1868

* This chapter was prepared by the senior author. It was printed and distributed in December, 1928.

by Worthen.[1] In a report of the Ohio Geological Survey for 1869 but published in 1871 Orton[2] called attention to a buried peat near Germantown, Ohio. Moreover, in the report of the Geological Survey of Ohio, Volume I, written in 1872, Orton[3] stated that the interglacial stage was coming to be clearly recognized both in Europe and in America. Another interesting early reference to the significance of vegetable material in relation to till was made by N. H. Winchell[4] in 1873. He stated that he found leaves and wood in clay in the midst of tills in southeastern Minnesota, and expressed the view that the clay "may consist of the remains of a previous glacial sheet, upon which rested vegetable growths of the surface, accumulating between the periods of glacial epochs." In the 3rd and 4th Annual Reports of the Geological and Natural History Survey of Minnesota, published in 1875 and 1876, respectively, Winchell described occurrences of two tills separated by peat, and in Geology of Minnesota, Volume I, 1884, he stated that in southeast Minnesota the peat separates an "old" drift or upper drift from an "older" drift or lower drift. At this time he recognized also in other parts of Minnesota a "younger" drift which is younger than his "old" drift.

Between the years 1875 and 1886 Chamberlin[5] published several important papers in which differences in topographic form and degree of alteration were emphasized as bases for differentiating tills. In fact he put greater emphasis upon the significance of these features than upon the forest beds. He recognized two tills in Wisconsin separated by a long interglacial interval. He called the older till the First Glacial and the younger the Second Glacial. In 1886 he stated that the subdivisions within each of these glacial epochs remained to be worked out but that some

1 Worthen, A. G., Ill. Geol. Survey, Vol. III, pp. 75 and 87, 1868.

2 Orton, Edward, Report for 1869, Ohio Geol. Survey, pp. 165-167, 1871.

3 Orton, Edward, Geology of Ohio, Vol. I, p. 430.

4 Winchell, N. H., The Surface Geology: Minn. Geol. & Nat. Hist. Survey, First Ann. Rep., pp. 61-62, 1873.

5 Chamberlin, T. C., The Extent and Significance of the Wisconsin Kettle Moraines: Wis. Acad. Sci., Trans., Vol. IV, pp. 201-234, 1878. (This paper was read about 1875.)

Le Kettle Moraine et les Mouvements glacieres qui lui ont donne naissance: Cong. Geol. Intrat. Sess., 1878. Compt. Rend. pp. 254-268, 1880.

The Bearing of some Recent Determinations on the Correlation of the Eastern and Western Terminal Moraines: Am. Jour. Sci., Vol. XXIV, pp. 93-97, 1882.

Geology of Wisconsin, Vol. I, pp. 271-272, 1883.

The Terminal Moraines of the later epoch: Am. Assoc. Adv. Sci., Proc., Vol. XXXII, pp. 211-212, 1883.

(With Salisbury) Preliminary paper on the Driftless Area of the Upper Mississippi Valley: U. S. Geol. Survey, 6th Ann. Rep., pp. 212-213, 1885.

An Inventory of our Glacial Drift: Am. Ass'n Adv. Sci., Proc., Vol. XXXV, pp. 195-211, 1886.

evidence of the older drift area pointed to a dual division of the first epoch.

From these splendid beginnings, investigations have continued year after year to the present time. As a result of these studies many chapters of the whole story of the Pleistocene of the Mississippi Valley have now been clearly outlined.

Early Work in Iowa by Owen, White, and McGee

Before the year 1850, D. D. Owen[6] considered the boulders of northeastern Iowa to have been "ice drifted by currents setting in from the north before the land emerged from the ocean." C. A. White[7] was apparently the first geologist to consider critically the drift phenomena of Iowa. He recognized the glacial origin of the material and referred some of the materials to their true sources. But it is to McGee that credit must be given for having made the first important contributions to the unraveling of the complex history of the glacial deposits of Iowa. In 1878 he[8] announced that the forest bed of northeastern Iowa was penetrated in wells, which showed that the vegetable deposits lay between tills and were therefore interglacial. McGee at this time must have been familiar with the work of Winchell in Minnesota on peat beds separating tills, and probably knew that Chamberlin in Wisconsin had differentiated two tills separated by an interglacial epoch, but he made no reference to their investigations. In 1879 McGee[9] published another paper in which he classified the superficial formations of northeastern Iowa. Included in his list of materials is sand and gravel with wood which constitutes his forest bed, which was ascribed to an interglacial epoch of long duration. Two years later, McGee[10] in a paper on the relations of geology to agriculture summarized the results of two type sections, one along the 92nd meridian in Iowa and the other along the 89th meridian in Illinois. This paper is of unusual interest, particularly because the glacial deposits of northeastern Iowa which in recent years have been the subject of

6 Owen, D. D., Report of a Geological Reconnaissance of the Chippewa land district of Wisconsin, and the northern part of Iowa: U. S. 30th Cong., 1st session, Doc. 57, p. 70, 1848.

7 White, C. A., Report on the Geological Survey of the State of Iowa, Vol. I, pp. 82-102, 1870.

8 McGee, W J, On the Relative Positions of the Forest Bed and associated drift formations in Northeastern Iowa: Am. Jour. Sci., Vol. XV, pp. 339-341, 1878.

9 McGee, W J, On the Complete Series of Superficial Formations in Northeastern Iowa: Am. Ass'n Adv. Sci., Proc., Vol. XXVII, pp. 198-213, 1879.

10 McGee, W J, The Relations between Geology and Agriculture: Ia. Hort. Soc., Trans., Vol. XVI, pp. 227-240, 1881.

much controversy are described and interpreted. He recognized two tills in northeastern Iowa, an upper till and a lower till, each of which has its own distinctive characteristics. In places his upper till is the surface till and in other places the lower till is at the surface. Where both tills are found in a section they are separated by a forest bed or by its stratigraphic equivalent—"hardpan" or "gumbo"—which he stated is the modified upper portion of his lower till. Since even to the present time there are some differences of opinion among geologists with regard to McGee's interpretation of the glacial deposits of northeastern Iowa, especially with reference to what constituted his forest bed horizon, it is well because of later discussions of this subject in this paper to emphasize here that McGee in his paper in 1881 made it clear that insofar as northeastern Iowa is concerned his "forest bed" and his "hardpan" or "gumbo" have the same stratigraphic position—that of separating his lower till from his upper till. It is well to keep in mind also that McGee interpreted the loess in northeastern Iowa and in areas farther south as equivalent in age to his upper till. Although he did not recognize that the gumbo on the till beneath the loess in southeastern Iowa is younger than the gumbo on his lower till in northeastern Iowa, nevertheless he described clearly the relationships of two tills with surface distribution in northeastern Iowa.

In 1891 McGee[11] published his final report on northeastern Iowa. This report was based on investigations begun in 1876. The field work was practically completed in 1881, and the greater part of the report was written during the ensuing winter. There was delay in publication until after the first topographic maps of the area were made, in 1887. During 1888 the territory was revisited by McGee, "and the entire work of the previous decade was reviewed." Then his original report was revived, brought up to date, and prepared for the press. This comprehensive work is the product of mature deliberation based upon investigations extending over a period of years, within which time his major interpretations were made known through the publication of papers in scientific journals, to some of which reference has already been made. It is well to emphasize again and again that McGee recognized only two tills in northeastern Iowa, his Upper

11 McGee, W J, The Pleistocene History of Northeastern Iowa: U. S. Geol. Survey, 11th Ann. Rep., pp. 199-586, 1891.

Till and his Lower Till, separated by a forest bed or "hardpan" (gumbo). The topographic and lithologic character, stratigraphic relations, and geographic extent of the Upper Till and of the Lower Till were described in detail. It was pointed out that his Upper Till is younger than the gumbo-surfaced drift (present Kansan drift) of southern Iowa and older than the till of the Des Moines lobe (present Wisconsin drift). McGee believed that the loess was aqueous in origin and correlated the abundant loess deposits in northeastern, southern, and southeastern Iowa with his Upper Till, calling them loess-drift or drift-loess.

It will be shown later in this paper that McGee did not differentiate in northeastern Iowa a third drift, which has no mappable surface distribution within this area but which has been exposed in a few places within his area, in railroad cuts and in road cuts, and has been penetrated in well drillings.

Chamberlin's Early Classifications

In August, 1893, Chamberlin[12] presented at the World's Congress of Geology a classification of the glacial deposits of the Mississippi Valley, in which he recognized a "Lowest till" separated from a "Second till and loess" by the first known interval. The "Second till and loess" is separated from a younger till with distinctive moraines by the "Post-loessial interval."

In the year 1893 Chamberlin and McGee visited the Afton Junction-Thayer region in Union county, Iowa, where they examined the now famous exposures of tills and gravels. They interpreted the chief gravels to be kamelike deposits closely associated with the till upon which the gravels lie.[13] Only at the Grand River pit was till exposed beneath the gravels. The till which lies on the gravels was considered by Chamberlin and McGee to have been deposited in connection with the second ice invasion. And now for the first time names were given to tills of different ages in Iowa. Chamberlin named the older of the two tills in the Afton Junction-Thayer region the Kansan till, and the younger till the East Iowan till. He believed that these two tills were of the same age as McGee's Lower Till and Upper Till, respectively, which had been mapped areally in northeastern

12 Chamberlin, T. C., Review of the Ice Age at the World's Congress of Geology: American Geologist, Vol. XII, pp. 223-231, 1893.

13 Chamberlin, T. C., in James Geikie's The Great Ice Age, pp. 753-764, 1894.

Iowa. He stated in Geikie's Great Ice Age, page 760, that "The designation East Iowan Formation is chosen because it has been most carefully worked out by Mr. McGee in northeastern Iowa and there displays its most distinctive features." At this time no name was given to the gravels separating the Kansan till from the East Iowan till in the Afton Junction region nor to the forest beds, peats, and soils, which in many places in Iowa were known to separate two tills and were interpreted to be the products of the first interglacial epoch.

Chamberlin, in referring in Geikie's Great Ice Age to the drift series in the Mississippi Valley, included a grouping on a three-fold basis. The three stages of glaciation were named from the oldest to the youngest "Kansan stage of glaciation," "East Iowan stage of glaciation," and "the East Wisconsin stage of glaciation." No names were given here for the intervals of de-glaciation.

In a review of Geikie's Great Ice Age, Upham[14] suggested that in Chamberlin's classification of the glacial deposits of North America the names East Iowan and East Wisconsin be shortened to Iowan and Wisconsin.

In 1895 Chamberlin[15] published a paper entitled "The Classification of American Glacial Deposits", in which he accepted Upham's suggestion and used the names Iowan and Wisconsin instead of East Iowan and East Wisconsin. In referring to the Kansan drift he stated that the term Kansan had been applied to the oldest drift because of its great extent in the direction of the arid plains and because it appeared in the state of Kansas free from complications with other formations. The name Aftonian was here used for the first time. The author's statement is as follows:

"Subsequent to the formation of the Kansan sheet of till and accompanying assorted deposits there was a notable retreat of the ice . . . . . During this stage of retreat there were accumulations of muck and peat reaching a reported depth of twenty-five feet. One of the best exposures of this horizon is found between Afton and Thayer, Iowa, and from the former a euphonious name may be taken. Owing to the scarcity of gravel in the drift territory of southern Iowa the Chicago, Burlington & Quincy Railroad has made extensive excavations upon these gravel deposits lying

14 The American Geologist, Vol. XV, p. 56, 1895.

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

between an upper sheet of till reaching a thickness of 40 to 60 feet and a lower till of less depth. The gravels appear to be kamelike accumulations, at least they are great lenses lying upon the surface of the lower till. This lower till is believed to belong to the Kansan stage and the upper to the Iowan. On the surface of the gravels there accumulated at points a deep mucky soil, in which occur considerable quantities of vegetable débris. This is believed to occupy the same horizon as the numerous peaty deposits described by McGee in eastern Iowa."

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

Iowan drift
Aftonian interval
Kansan drift and associated gravels.

Chamberlin's classification of the glacial and interglacial deposits at this time was as follows:

5. Wisconsin drift
4. Toronto interglacial deposits
3. Iowan drift
2. Aftonian interglacial deposits
1. Kansan drift.

The interval between the Iowan and Wisconsin stages of glaciation was provisionally named Toronto because of excellent exposures of interglacial fossiliferous beds along the Don valley in Toronto, Ontario, which it was thought might prove to be of this age although it was recognized that the grounds for this correlation were not very strong.

Dawson's Albertan Drift and Its Relations to the Drifts of the Mississippi Valley

In the year 1895 Dawson[16] described a general section of the drift deposits of southwestern Alberta, Canada, in which he cor-

16 Dawson, G. M., Note on the Glacial Deposits of Southwestern Alberta: Jour. Geol., Vol. III, pp. 507-511, 1895.

related two boulder clays in his region with the Kansan and Iowan of McGee's area. Moreover, in his region he found gravels older than the Kansan and derived from "western" boulder clay. He stated:

"According to the scheme of classification suggested above it will be observed that the western boulder clay must represent an epoch of glaciation antecedent to the Kansan. There can be but little doubt that this corresponds with the time of maximum development of the Cordilleran ice sheet, but as there was at least one subsequent epoch of important development of this ice sheet I would suggest that this stage may be named 'Albertan'. The Albertan 'formation' to comprise both the 'western' boulder clay and the derived 'Saskatchewan gravels'."

Early Mapping of Kansan and Iowan Drifts and Related Materials by Members of the Iowa Geological Survey

The present Iowa Geological Survey was organized in 1892 with Samuel Calvin as State Geologist. In December, 1894, Norton[17] submitted for publication by the Survey a report on the geology of Linn county, which is within the northeastern Iowa area described by McGee. Here Norton described two tills, the Lower Till or Kansan till and the Upper Till or East Iowan till. His differentiation of these two tills was in accordance with McGee's description of these two tills. In referring to McGee's work on the drift he said:

"It has been so thoroughly interpreted by McGee that only supplementary notes need be given here."

In the same annual report of the Iowa Geological Survey, Gordon[18] described the till of Van Buren county as being Lower Till.

During the field season of 1895 the Iowa geologists mapped the Lower and Upper tills, the Kansan and the Iowan, respectively, within McGee's northeastern Iowa area and in areas to the south, southwest, and west of this area. In a report on the geology of Jones county Calvin[19] stated:

"The superficial deposits of Pleistocene origin are somewhat complex. They embrace (1) two sheets of till known respectively as the Kansan and Iowan drift; (2) some beds of water-laid sands and gravels that are

[17] Norton, W. H., Geology of Linn County: Iowa Geol. Survey, Vol. IV, pp. 168-174, 1895.

[18] Gordon, C. H., Geology of Van Buren County, Iowa: Iowa Geol. Survey, Vol. IV, p. 206, 1894.

[19] Calvin, Samuel, Geology of Jones County: Iowa Geol. Survey, Vol. V, pp. 63-70, 1895.

probably interglacial or Aftonian in age; (3) beds of loess, clays, and associated sands that overlie both first and second till, and are connected genetically with events taking place between, and in front of, the ice lobes developed along the attenuated margin of the Iowan glaciers; and (4) alluvial beds of clay, sand and gravel of more recent origin, deposited on the flood plains of the streams. The Kansan drift is quite generally concealed by the newer till. It is seen, however, in a few natural exposures where rain water has cut through the thin Iowan drift or in places where the second drift has been bodily removed."

In referring to the Iowan till he stated that it is superficial over the larger part of the drift plains, and that its thickness rarely exceeds twenty feet, and generally it is much less. He described the differences between the Kansan till and the Iowan till, and proposed the name Buchanan gravels for the yellowish, stratified, generally cross-bedded sands and gravels which in places separate these two tills, and which Calvin at this time thought were of the same age as the Aftonian gravels at Afton Junction in Union county.

In a report on the geology of Washington county Bain[20] described the Kansan drift and stated:

"No well defined forest bed which can be traced from place to place has been found."

He considered the loess which overlies the Kansan till to be Iowan in age. In his report on Appanoose county, Bain[21] described the drift of that county as Kansan drift.

Tilton,[22] in a report on the geology of Warren county, described the Kansan drift, which he stated:

"Extends over the southern and western part of Iowa."

In 1896 Calvin[23] published a paper on his Buchanan gravels. He stated:

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

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20 Bain, H. F., Geology of Washington County: Iowa Geol. Survey, Vol. V, pp. 152-156, 1895.

21 Bain, H. F., Geology of Appanoose County: Iowa Geol. Survey, Vol. V, pp. 406-408, 1895.

22 Tilton, J. L., Geology of Warren County: Iowa Geol. Survey, Vol. V, pp. 317-320, 1895.

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

Again he stated:

"Overlying the gravel is a thin layer of Iowan drift not more than two or three feet in thickness, but charged with gray granite boulders of massive size . . . . . The surface of the whole surrounding region is thickly strewn with Iowan boulders. It is evident that the Iowan drift sheet was spread over northeastern Iowa after the gravels were in place."

In the same year, 1896, Shimek[24] put forward the theory that the loess in Iowa is not aqueoglacial in origin, as had been believed, but is eolian. He presented fossil, textural, and topographic evidence to support his view.

As has been stated, the early classifications of the drift deposits of Iowa recognized only two drift sheets older than the Wisconsin drift. And these two drift sheets, the Kansan and the Iowan, had been mapped with but little difficulty in several counties in Iowa by members of the Iowa Geological Survey, from McGee's descriptions of his Lower and Upper tills in northeastern Iowa. The Des Moines lobe was recognized as belonging to the Wisconsin drift. The Iowan was given no definite limits to the south of McGee's area, but Chamberlin and McGee had considered it to be present south of Des Moines in Union county.

Bain's Correlation Studies

Bain[25] stated:

"In 1895 Calvin began his work in Johnson county and quickly recognized that the drift sheets present in the northern and southern portions of the county, respectively, were radically different in age. If the surface drift of the paha region were Iowan, that of southern Johnson county must be something earlier, and he accordingly referred it to the Kansan. After spending some days in Johnson county in company with Professor Calvin, the present writer extended the work into Washington county and assigned the drift there to the Kansan and the loess to the Iowan. These were known to be in all respects identical with that previously studied in Keokuk and Mahaska counties, and present throughout much of the southern portion of the state, and accordingly the deposits of Appanoose and Warren counties were placed with those of Washington."

In the same paper he stated:

24 Shimek, B., A Theory of the Loess: Iowa Acad. of Sci., Proc., Vol. III, pp. 82-89, 1896.

25 Bain, H. F., Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa, and Related Phenomena: Iowa Geol. Survey, Vol. VI, pp. 463-464, 1896.

"Since the upper drift at Afton had been considered to be Iowan a number of visits to the locality were made for the purpose of studying the relations of the drift sheets at that point. The drift in Polk county was traced southward and found to be the same as the upper drift at Afton Junction. At the latter point it showed the upper zone of ferrugination, the leaching, the weathered boulders, and all the physical characteristics which had come to be recognized as peculiar to the Kansan in the surrounding region. Its relations to the loess were the same, as was also its topographic development. In short, the upper drift at Afton was found to be the same as that which was elsewhere recognized as Kansan, and a still lower pre-Kansan drift sheet was recognized.

"The pre-Kansan drift is probably the equivalent of the Albertan as described by Dawson, though the connection has not yet been worked out and quite probably never can be placed beyond dispute."

Revision of Early Classifications

Chamberlin[26] in an editorial in the Journal of Geology discussed the glacial deposits of the Mississippi Valley in relation to the new facts which had been discovered by Bain. He stated:

"The investigations of the Iowa geologists have led to the quite firm conviction that the upper till sheet of the series in southern Iowa is the lower member in eastern Iowa . . . . . . In harmony with these views the upper till in southern Iowa has been designated Kansan in the recent Iowa reports.

"During the past summer I have had the pleasure of making two excursions with Mr. Bain of the Iowa Survey to localities where the above formations are advantageously exhibited, and I have been impressed with the cogency of the arguments of the Iowa geologists. While, therefore, the case cannot be said to be demonstrative, as yet, it seems best to accept the application of the nomenclature adopted by the Iowa Survey. This places the Aftonian beds below the Kansan series instead of above them."

In a later part of the editorial he gives the Pleistocene series in the Mississippi Valley as modified and included the Illinoian till sheet which had been determined by Leverett to have invaded Iowa from Illinois at some time between the Kansan and the Iowan. Chamberlin stated:

"The series in the Mississippi basin, as thus modified, would be as follows in stratigraphic order:

26 Chamberlin, T. C., Editorial, Jour. Geol., Vol. IV, pp. 872-876, Oct.-Nov., 1896.

9. Wisconsin till sheets (earlier and later).
8. Interglacial deposit (Toronto, perhaps).
7. Iowan till sheet.
6. Interglacial deposit.
5. Illinoian till sheet (Leverett).
4. Interglacial deposits (Buchanan of Calvin).
3. Kansan till sheet.
2. Aftonian beds. Interglacial.
1. Albertan drift sheet."

In this paper Chamberlin gave also a system of time ratios based upon his impression of the relative amounts of erosion and weathering of the drifts. His ratios were as follows: Time since close of Wisconsin 1 unit, since earliest Wisconsin moraine 2 1/2 units, since Iowan 5 units, since Illinoian in Iowa 8 units, and since Kansan 15 units. No attempt was made to estimate the age of the pre-Kansan drift.

In 1897 Calvin[27] summarized the Iowa formations as follows:

"I. First stage of glaciation, *Albertan.* Invasion of Iowa by glaciers and distribution of lowest sheet of till.

II. First interglacial stage, *Aftonian.* Melting and retreat of glaciers and deposition of gravels, followed by a long period of forest growth, development of soils, and modification of the original drift.

III. Second glacial stage, *Kansan.* Cold more intense and glaciation more general than during the first stage. Distribution of McGee's lower till.

IV. Second interglacial stage, *Buchanan.* Introduced by deposition of gravels in Buchanan, Black Hawk, Floyd, Cerro Gordo and other counties. This stage was very long and the surface of the second drift sheet was profoundly modified by erosion, oxidation and leaching before it came to a close.

V. Third stage of glaciation, *Illinois.* During this stage only a small part of Iowa, embracing portions of Louisa, Des Moines, and Lee counties, was invaded by glaciers. The ice came from the northeast, bringing boulders from the eastern shores of Lake Huron.

VI. Third interglacial stage (unnamed), during which the modification of the second drift sheet proceeded over the greater portion of Iowa. The small area occupied by the third deposit of drift also suffered more or less of modification.

VII. 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. It

27 Calvin, S., Iowa Geol. Survey, Vol. VII, 18, 19, 1897; Amer. Geol. XIX, 270-272, 1897. Annals of Iowa (3), III, No. 1, 1-22, 1897.

was during this stage that the enormous granite boulders so conspicuous in Bremer, Black Hawk, Buchanan and other counties in northeastern Iowa were transported and deposited where they now lie.

VIII. Fourth interglacial stage, *Toronto* (?) This fourth interglacial stage was short as compared with the second, and probably with the third. The amount of erosion, oxidation and leaching that during this interval took place in the surface of the fourth sheet of drift is altogether inconsiderable. The amount of change that has taken place since the beginning of the interval up to the present time is comparatively small.

IX. Fifth glacial stage, *Wisconsin.* The last invasion of Iowa by glacial ice occurred in times so recent, geologically speaking, that the youngest sheet of till exists practically in the condition in which the glaciers left it. The area in Iowa affected by this last invasion is nearly triangular in shape, the base of the triangle coinciding with the north line of the state from Worth to Osceola counties, with the apex located at Des Moines. In the northern part of this area there are numerous stretches of ill-drained lands, the surface is only very gently undulating and the stream channels, where defined at all, have cut only a foot or two into the prairie sod.

X. The recent stage, since the retreat of the Wisconsin ice, brings Pleistocene history down to the present. The recent stage, while long as measured in years, has been too short to produce any appreciable effect in the surface of the Wisconsin drift."

In the light of subsequent discussion in this paper of the drift west of the Des Moines lobe of Wisconsin drift in northwestern Iowa it is of interest to state here that during the summer of 1896 Professor Salisbury, who was connected with the United States Geological Survey and in charge of the Pleistocene work of the Geological Survey of New Jersey, "accompanied Mr. Bain upon a short trip across the northern part of the state, going as far west as Sioux City and Rock Rapids. The topographic characteristics of the Iowan and the Wisconsin were studied and the probable equivalence of the drift sheets east and west of the Des Moines lobe was tentatively decided upon."[28]

First Discovery of Pre-Kansan Drift in Northeastern Iowa, in 1896

It is well to emphasize again that McGee described only two drifts in northeastern Iowa, and that for some time the Iowa

28 Calvin, S., Administrative Report, Iowa Geol. Survey, Vol. VII, p. 20, 1897.

Geological Survey had mapped only these two drifts in this area, McGee's Lower Till and Upper Till, the Kansan and the Iowan, respectively. Furthermore, for some time it had been thought that the two drifts in the Afton Junction region were the Kansan and the Iowan, but it had later become the consensus of opinion that the upper drift in this region was the Kansan drift of McGee's area and that the Aftonian of the Afton Junction region lay below this Kansan drift and above the drift which had been named Kansan by Chamberlin but which after the shifting of names was designated the pre-Kansan or sub-Aftonian, or, on the basis of Dawson's oldest drift, the Albertan. But in the summer of 1896 a very significant section was made available for study in a new railroad cut on the Chicago Great Western railway southeast of Oelwein, in Fayette county, which is in the heart of McGee's area. This section was described in a series of papers[29] by Finch, Beyer, Macbride, and Calvin.

The section as given by Beyer is as follows:

"5.	Boulder clay, rather dull-yellow in color; the upper portion is modified into a thin soil layer. Large boulders, mainly of the granitic type, are present, often resting on or partially imbedded in the deposits lower in the series. (Iowan)	0–10 feet
4.	Sand and gravel—not a continuous deposit; often shows water action expressed in parallel stratification lines and false bedding. The gravels are usually highly oxidized and fine textured. (Buchanan)	0– 2 feet
3.	Till, usually bright-yellow above, graduating into a gray-blue when dry or a dull-blue when wet, below. This deposit is massive and exhibits a tendency to joint when exposed. Decayed granitic boulders are common. (Kansan)	3–20 feet
2.	a) Sand, fine-white, well water-worn; often with a slight admixture of silt and clay. (Aftonian)	0– 6 inches
	b) Vegetal layer and soil, from two to four inches of almost pure carbonaceous matter, with one to three feet highly charged with humus. The peaty layer often affords specimens of moss (Hypnum) perfectly preserved. (Aftonian)	0– 4 feet
1.	Till, greenish-blue when wet or gray-blue with a greenish cast when dry. Greenstones and vein quartz pebbles predominate. (Sub-Aftonian or Albertan.) Exposed	10 feet"

The three tills were interpreted to be, from the oldest to the youngest, the pre-Kansan, the Kansan, and the Iowan. The peat bed separating the pre-Kansan and Kansan tills was believed to be Aftonian, and the sands and gravels separating the Kansan till from the Iowan till to be Buchanan.

29 Finch, G. E., Drift Section at Oelwein, Iowa: Proc., Iowa Acad. Sci., Vol. IV, pp. 54-58, 1897; Beyer, S. W., Evidence of a Sub-Aftonian till sheet in Northeastern Iowa: idem, pp. 58-62; Calvin, Samuel, Summary of above papers: idem, pp. 66-68.

In a paper presented by Calvin[30] at the Des Moines meeting of the Iowa Academy of Science in December, 1897, the views of the Iowa geologists at this time were clearly expressed as follows:

"Our knowledge of Pleistocene geology has moved with tremendous strides during the past two years. A review of its progress would occupy more space than can be given in this paper. A few points, however, must be noted. First, Bain showed that the till overlying the Aftonian beds was Kansan, the Lower Till of McGee, and not the Iowan, or Upper Till, as had been assumed. This observation rendered necessary a series of adjustments in views previously entertained. A new drift sheet was added to the glacial series of this region, and the Aftonian and Buchanan beds were shown to lie at different horizons. Before the adjustment Chamberlin had published his classification of American glacial deposits which recognized the Kansan, Iowan, and Wisconsin as the only glacial stages that had been worked out with any satisfactory degree of definiteness. It was in these early publications that the Aftonian beds were referred to the interval between the Kansan and the Iowan. The adjustment following Bain's demonstration of the true position of the Aftonian left the Buchanan gravels as the only recognized deposit so far published representing this interval, and the term Buchanan offered itself as a convenient designation for the second interglacial stage."

Regarding the use of this term he stated:

"The use of the term Buchanan as a name for an interglacial stage is open to criticism. It came into use tentatively before the recognition of the Illinoian drift as a stage distinct from either Kansan or Iowan had been published, and when the whole period of time between the retreat of the Kansan and the invasion of the Iowan ice was supposed to be a single, uninterrupted, interglacial interval. It was first used in the precise sense in which the term Aftonian was originally used, and as a substitute for that term when it was shown that the Aftonian soils and gravels preceded the Kansan stage. Since the recognition of the Illinoian glacial stage the term has been used for the interval following the Kansan in publications by Chamberlin, Calvin, and Scott. No great objection to its continued use can be urged. In fact, it is much to be desired that names once introduced should remain undisturbed, but it may after all be a decided gain to Pleistocene geology to select a name for the interval between the Kansan and Illinoian from some locality where true interglacial deposits are clearly intercalated between the Kansan and Illinoian sheets of drift."

30 Calvin, S., The Interglacial Deposits of Northeastern Iowa: Iowa Acad. Sci., Vol. V, pp. 64-70, 1898.

In this same paper he stated also:

"McGee looked upon the forest bed as the plane of division between his lower and upper till, but later investigators following the lines which he pointed out have reached the conclusion that his lower till embraces two distinct drift sheets, and that it is between these two that the forest bed invariably lies. Thus there are three drift sheets in northeastern Iowa, and in the recent literature referring to Pleistocene geology they are known respectively as Sub-Aftonian or Albertan, Kansan and Iowan. No forest material has been observed between the Kansan and the Iowan, but in this situation there occur extensive beds of stratified sands and gravels."

Calvin believed that in northeastern Iowa the forest bed was "invariably" between the sub-Aftonian and Kansan tills. It will be shown later that a "forest bed" is present also in many places at the same stratigraphic horizon as the sands and gravels separating the Kansan and the Iowan. Between the Kansan and Iowan in many places there is the "gumbo" (Kansan gumbotil) which McGee correlated with his forest bed between his Lower and Upper tills.

It is well to refer here to the fact that after the discovery of the Oelwein section, in which there were three drifts exposed with a distinct forest bed between the lowest drift and the intermediate drift, there were some geologists who believed and who still believe that this forest bed was McGee's forest bed separating his Lower Till from his Upper Till and that since the names Kansan and Iowan had been given to these two tills the lowest till at the Oelwein cut should have been given the name Kansan and the till above the forest bed there should have been given the name Iowan, and that a new name should have been given at this time to the thin till which had been mapped widely in Iowa as Iowan. On this point there was some doubt in the minds of some of the geologists of the Iowa Geological Survey. For instance, Bain[31] stated:

"The Kansan has heretofore been correlated with the lower till as recognized by McGee,[32] but certain recent observations seem to indicate that the latter may find its correlative in the pre-Kansan rather than the Kansan. At Oelwein in Fayette county, some excavations made by the

31 Bain, H. F., Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa, and Related Phenomena: Iowa Geol. Survey, Vol. VI, pp. 466-467, 1896.

32 Chamberlin, T. C., Journ. Geol., III, 273, 1895.

Chicago Great Western Railroad have revealed the presence of a well developed till below the Kansan and separated from it by an important peat bed. Above the Kansan the Iowan is characteristically displayed though its thickness is small. The three drift sheets with representatives of the Buchanan and Aftonian interglacial beds are shown in the one section. A review of sections published by McGee makes it more than doubtful whether the forest bed which he has so clearly shown to be present does not mark the Aftonian rather than the Buchanan horizon."

However, there is good argument in defense of the policy which has been followed by the Iowa Geological Survey, as has been shown in papers published by Calvin. Moreover, recent field study in McGee's area has revealed evidence which indicates that the name Iowan has been used and is now being used for McGee's Upper Till and the name Kansan for McGee's Lower Till if proper emphasis is given to his descriptions of his two tills, the mapping of his two tills and his forest bed or gumbo rather than too great stress given to his forest bed alone as has been the tendency of some geologists to do. At the time the Oelwein cut was described gravels and sand only had been found by Calvin and his assistants in sections separating the Iowan from the Kansan, whereas McGee emphasized the number of well records in which a forest bed separated his Lower Till from his Upper Till. Since, as stated above, it is now known that in McGee's area there is in places a forest bed at the same stratigraphic horizon as the Buchanan sands and gravels and a forest bed at the stratigraphic horizon of the Aftonian, quite naturally McGee's forest bed in some of his sections is the forest bed between the Kansan and the Iowan, as these names are now applied, and in others the forest bed lies between the Kansan and the pre-Kansan. It is not surprising that McGee, a pioneer in Pleistocene studies, did not correctly interpret all the materials of the region in which his investigations were carried forward. He was in error, as were others of his day, in the interpretation of loess as being primarily of aqueous origin rather than of eolian origin. He correlated the loess with his Upper Till, calling it in places loess drift or drift loess. Moreover, as has been stated, he recognized only two tills in an area where it has been determined that there are three tills. He called his tills Upper Till and Lower Till and emphasized their separation by a forest bed or gumbo. His failure to identify the third drift is not vital to his argument as to his Upper Till. It is probable that in some of his well records the forest bed did correctly delimit this upper till. It is also undoubtedly true that in other records he included two tills above his forest bed. Furthermore, one is forced to the judgment from our present knowledge of the area that his forest bed lay in places within a single till which was elsewhere either his Upper or his Lower till. From the descriptions in the text the precise nature of the forest bed is not made clear. This is true especially of the forest bed described in wells in his chart and in his table. He stated:

"In no case in which the testimony was doubtful or conflicting or inconsistent with the character of the surface has the record been introduced."

Thus, there is indicated a selection of records, the basis for which is given only in general. There was necessity also for the interpretation of statements as to the character of the material and other facts for

"several of the sections are based on information derived from other observers, and a number of wells were reached immediately after completion or while walling up was in progress, and while yet the materials thrown out were fresh and unaltered; and in such cases the statements of intelligent owners or excavators as to thickness of members, etc. were usually accepted, unless the phenomena differed in kind or essentially in degree from those personally observed."

These facts do not make the data of his well sections invalid. They only argue caution in interpretation in relation to the facts known today in this area. From the data given in McGee's report alone it seems almost as absurd to correlate a particular well shaft exposure of a forest bed with a particular interglacial horizon as to identify tills from two or more drift sheets by means of hand specimens.

Practically all the well sections in McGee's report are of wells more than twenty-five feet deep. A study of nearly 200 given well sections shows that 40 per cent of them have the forest bed described. In a large majority of the cases this forest bed line or the lower till surface where there is no forest bed is drawn within thirty feet of the top of the drift. The well sections may be divided into two classes. One group is located outside the present area mapped as Iowan till, and the Aftonian horizon may be represented—but in these wells the forest bed is usually absent and the distinction is made on the basis of till color and consistency. The other group lies within the Iowan area, and because of the known presence of Kansan gumbotil over wide areas, the thinness of the Iowan till, and the striking difference between the Iowan till and the gumbotil, the forest bed horizon here may properly be interpreted to represent the Kansan gumbotil horizon. The unconvincing character of the well records renders it unwise to make definite assertions as to McGee's interpretations. But independently of well records there is no doubt that there is an upper widespread till sheet geographically, stratigraphically, and topographically distinct in northeastern Iowa and resting on an older till which too has its own distinctive features. The upper of these two tills has long been mapped as Iowan and the lower as Kansan.

Introduction of Terms Yarmouth, Sangamon, and Peorian for Interglacial Stages

In 1898 the names Yarmouth, Sangamon, and Peorian were introduced into the classification of Pleistocene deposits in the Mississippi Valley by Leverett.[33] The name Yarmouth was applied to the soil and weathered zone at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and Quincy, Illinois. Leverett stated:

> "The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason, and because the name of this village is less likely to be confusing than names which are common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth not only a soil horizon but apparently a pronounced erosion between the Illinoian and Kansan sheets."

The name Sangamon was applied to the soil horizon between the Illinoian till sheet and the Iowan loess. The first recognition

33 Leverett, Frank, The Weathered Zone (Yarmouth) between the Illinoian and Kansan till sheets: Jour. Geol., Vol. VI, pp. 238-243, 1898; Iowa Acad. Sci., Proc., Vol. V, pp. 81-86, 1898.
The Weathered Zone (Sangamon) between the Iowan loess and Illinoian till sheet: Jour. Geol., Vol. VI, pp. 171-181, 1898; Iowa Acad. Sci., Proc., Vol. V, pp. 71-81, 1898.
The Peorian Soil and Weathered Zone (Toronto formation ?): Jour. Geol., Vol. VI, pp. 244-249, 1898.

of the occurrence of this definite soil horizon was reported by A. H. Worthen. In his report on Sangamon county, Illinois, made in 1873, he called attention to a soil found at the base of the loess in Sangamon and neighboring counties. The name Sangamon was taken from this locality where the soil was first reported.

The name Peorian was applied to the weathered zone at the contact between the Iowan loess, which was correlated with the Iowan till, and the Wisconsin till in the region of Peoria, Illinois. It will be recalled that Chamberlin in 1895 used provisionally the name Toronto for the interval between the Iowan and Wisconsin stages of glaciation because of excellent exposures of interglacial fossiliferous beds along the Don Valley in Toronto, Ontario, which he thought might prove to have this age. He recognized that the grounds for this correlation were not very strong and suggested that some less well developed and less known deposits might have to be looked to as a type of this interglacial horizon if the Toronto beds should prove to be unavailable. Leverett, in view of the uncertainty attached to this correlation, felt that it was advisable to employ a substitutional name which was applicable to the interval between the Iowan and Early Wisconsin. The name Peorian was used since in exposures east of Peoria, Illinois, there is decisive evidence of an interval of some length between the deposition of the loess which was correlated with the Iowan till and the Shelbyville till sheet, which appeared to be the earliest of the Wisconsin series.

Leverett's Illinois Glacial Lobe

In 1899 Leverett's monograph on the Illinois Glacial Lobe appeared.[34] In this publication the classification of the Pleistocene deposits is given as follows, from the oldest to the youngest:

(1) Oldest recognized drift sheet, Albertan of Dawson, and sub-Aftonian of Chamberlin; (2) Aftonian; (3) Kansan drift; (4) Yarmouth interval; (5) Illinoian drift; (6) Sangamon interval; (7) Iowan drift and main loess deposit; (8) Peorian, possibly equivalent to Toronto of Chamberlin; (9) Early Wisconsin morainic drift; (10) unnamed interval shown by shifting of ice lobes; (11) Late Wisconsin morainic drift; (12) (13) (14) and (15) stages of Lake Chicago as given in an earlier publication.

34 Leverett, Frank, The Illinois Glacial Lobe: U. S. Geol. Survey, Mon. 38, 1899.

Comparison Between Work of Last Quarter of the Nineteenth Century and Work Since About the Beginning of Present Century

It is of interest to point out here that, whereas at the beginning of the last quarter of the nineteenth century students of Pleistocene glacial deposits in America were beginning to discover evidence which caused them to believe that there had been more than one glacial epoch, by the end of the century there was general agreement among the glacial geologists who had studied in Iowa and adjacent states that the evidence justified the interpretation that the Pleistocene history had been long and complex, embracing five glacial stages and four interglacial stages, each of which had been named and described. From about the beginning of the present century until now the drift sheets and interglacial deposits have been subjected to detailed study, the results of which have given clearer conceptions of the various epochs of the Glacial Period and of the Period as a whole than were possible earlier. Former views have been modified and refined and a better understanding has been reached with regard to many intricate problems, some of which have been explained satisfactorily, whereas others still await solution. Some of the chief investigations with their results will be presented.

The Iowan Drift Described by Calvin

In the year 1899 Calvin published a paper[35] in which he described fully the features of the Iowan drift which differentiate it from the other drift sheets of the Mississippi Valley. The paper refers to many aspects of the Iowan, including (1) the origin of the name Iowan; (2) the area occupied by the Iowan drift sheet; (3) the characteristics of the Iowan drift—the topography, color and composition of the till, its boulders, etc.; (4) relation of the Iowan to the "Forest Bed" of northeastern Iowa; (5) comparison of the Iowan with the Kansan, the Illinoian and the Wisconsin tills; and (6) the Iowan margin, including a discussion of its sinuosities and digitations, the loess ridges along its margin, etc.

In this paper he explained the confusion which had arisen as a result of a third drift having been found in northeastern Iowa,

35 Calvin, Samuel, Iowan Drift: Bull. Geol. Soc. of America, Vol. 10, pp. 107-120, 1899.

the region about which McGee had written in terms of two tills only. He pointed out that the till to which the name Iowan was being applied had all the characteristics of McGee's Upper Till. In his discussion of the relation of the Iowan to the "Forest Bed" of northeastern Iowa, he made the following statement:

"Remains of a forest bed which was overwhelmed and buried by advancing glaciers are conspicuous in many of the drift sections in northeastern Iowa. The abraded and splintered wood is distributed through a zone a number of feet thick, but it is most abundant in connection with, or just a little above, a definitely marked soil band and peat horizon. The principal belt through which forest material is distributed lies above the soil and peat. The soil band, peat beds, and forest remains are all evidence of an interglacial age of longer or shorter duration, for there is a heavy underlying till sheet that is older than either soil or forest. Accordingly, in dividing the Pleistocene deposits of the region under consideration into a lower and an upper till, it was most natural that the soil, peat, and forest horizon should be adopted as the line of separation. For some time after the sheet of till we now call Kansan had been differentiated from the true Iowan by evidences of erosion and weathering, the belief in a forest bed below the Iowan and above the Kansan was still entertained. The differentiation of the Iowan and Kansan till sheets was made as the result of studies carried on along or near the margin of the Iowan drift. The two deposits were strikingly different. That they were separated by an immensely long interglacial interval was as clear as noonday. It was the unquestioned belief when the names Kansan and Iowan were applied to the two drifts we are now considering that one was the upper till and the other the lower till of McGee, and that they were the formations to which the names Iowan and Kansan had been applied by Chamberlin. If there was a forest and soil bed, it must be between these two deposits, for as yet there was no evidence that there were more than two deposits to be taken into consideration. Gradually, however, as available sections were multiplied and opportunities for study were enlarged, it was found that the forest bed and soil band were invariably located beneath the drift we had been calling Kansan, and that no section anywhere revealed the presence of forest material immediately beneath the typical Iowan. A ferretto zone is there, with most convincing evidence of prolonged and profound weathering, but no soil band, no buried forest—at least, none in any way comparable with the wealth of vegetable matter buried in and beneath the drift we have all learned to call Kansan. The forest zone separates the Kansan of the later literature relating to the Pleistocene from the oldest drift of the region, so far as known, from the lately added member of our Glacial series—the pre-Kansan or sub-Aftonian till."

As stated before, the author of this paper will present evidence in subsequent pages to show that Calvin was in error in his belief that forest beds are present only at one horizon, namely, separating the sub-Aftonian from the Kansan. Recent investigations in McGee's type area have shown that at many places there is organic material—a forest bed—above the Kansan and below the Iowan. In fact, the number of known exposures of a forest bed or of McGee's equivalent, "the gumbo," is far greater between the Kansan and the Iowan than between the pre-Kansan and the Kansan in northeastern Iowa.

It is of interest to note here in the light of subsequent discussions in this paper that Calvin thought that the Kansan drift was certainly 15 and possibly 50 times as old as the Iowan; that judging by the changes that had been wrought in the surface of the Illinoian before the loess was laid down on it, this sheet of till is at least five or six times as old as the Iowan, and that the Iowan was "not more, or certainly not much more than twice as old as the Wisconsin."

Reports on Many Iowa Counties, and Other Geological Publications

During the years 1896 to 1909 inclusive the members of the Iowa Geological Survey published reports on many counties in Iowa,[36] including Johnson, Cerro Gordo, Marshall, Polk, Guthrie, Madison, Dallas, Delaware, Buchanan, Decatur, Plymouth, Carroll, Humboldt, Story, Muscatine, Scott, Lyon and Sioux counties, Osceola and Dickinson counties, Hardin, Worth, Dubuque, Louisa, Marion, Pottawattamie, Cedar, Page, Clay and O'Brien counties, Webster, Henry, Cherokee and Buena Vista counties, Jefferson, Wapello, Howard, Kossuth, Hancock and Winnebago counties, Mills and Fremont counties, Tama, Chickasaw, Mitchell, Monroe, Benton, Emmet, Palo Alto and Pocahontas counties, Jasper, Clinton, Fayette, Winneshiek, Clayton, Bremer, Black Hawk, Franklin, Sac and Ida counties, Jackson, Butler, Grundy, Hamilton and Wright counties, Iowa, Wayne, Poweshiek, Harrison and Monona counties, and Davis county.

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36 Reports of Iowa Geological Survey, Vols. VI to XX inc.

In these reports there is much detailed information regarding the tills and interglacial materials in these counties. In the Polk county report, in Volume VII, Bain stated that the Kansan and Wisconsin tills are present and possibly the pre-Kansan. He believed that a gumbo clay on the Kansan in Polk county and in Decatur county was the result of water deposition. The same author in his report on Plymouth county, in Volume VIII, referred to the difficulty in classifying, in northwestern Iowa, the drift of the area west of the Des Moines lobe of Wisconsin drift. He thought the evidence favored the interpretation that the drift is Iowan or Illinoian in age. Wilder in his report on Lyon and Sioux counties, in Volume X, found far less leaching of the drift in northwest Iowa than had been found elsewhere. He thought it best to correlate this drift with the Kansan although it resembled the Iowan topographically. Macbride in his report on Cherokee and Buena Vista counties, in Volume XII, referred to the drift outside the Wisconsin moraine, and stated that its age "is still a matter of conjecture." Calvin in his report on Delaware county, in Volume VIII, referred to the Iowan as overlying weathered gravels and weathered Kansan till and to "islands" of loess-covered Kansan till inside the Iowan areas. In his report on Buchanan county, in Volume VIII, he described the Buchanan gravels. He referred to an upland phase in which the materials are relatively coarse and a valley phase composed largely of sand and fine gravels. In his report on Howard county, in Volume XIII, he referred again to the upland and valley phases of the Buchanan gravels and expressed the view that the upland gravels were deposited from streams flowing on the higher areas which had become bare while yet bodies of ice filled the valleys and lowlands. Then after the ice melted from the valleys the valley gravels were laid down. In his report on Howard county he referred also to loess on the Iowan as being so rare as to excite surprise, and in his report on Winneshiek county, in Volume XVI, he referred to the "very erratic and curiously lobulate character of the margin of the Iowan drift sheet." Savage in his report on Tama county, in Volume XIII, referred to the boulders on the Iowan and expressed the view that the Iowan outline could almost be mapped from the presence of boulders.

In the Muscatine and Scott county reports, in Volume IX, there are detailed descriptions of the Illinoian drift.

In the year 1904, Shimek[37] published several papers in which he presented his views regarding many aspects of loess. He pointed out that there is no transition between drift and loess, that there are loesses of different ages, and in referring to the loess in relation to the Iowan drift he stated that the thickening of the loess and its association with the sand dunes along the Iowan border was no different than along several of the main streams where no connection with Iowan drift could possibly be claimed. In the same year Savage[38] described a buried peat bed of Aftonian age separating the pre-Kansan and Kansan tills in Union county, the county in which the famous cuts near Afton Junction are located. This peat bed has the same relationship to till as the peat bed in the cut at Oelwein in Fayette county.

Between the years 1900 and 1905 the Chicago, Burlington and Quincy Railroad made some important changes in the road between Thayer and Afton in Union county, in connection with which numerous deep cuts in drift were made, affording an unusual opportunity for the study of the glacial deposits. These new cuts as well as the Afton Junction, Grand River, and Thayer gravel pits were studied carefully by Calvin. The results of his investigations were given in a paper published by the Davenport Academy of Science.[39] In this paper, on page 21, he stated:

"There are three possibilities: (1) the gravels may have been laid down along drainage courses by waters flowing away from the melting and retreating margin of the pre-Kansan ice, upon a surface which but a short time before had been left bare by the gradually waning glaciers . . . . . . (2) The gravels may have been deposited by waters flowing out in front of the advancing Kansan ice, in which case they were laid down upon the eroded and weathered surface of the pre-Kansan till . . . . . . (3) The gravels may have been deposited by floods which were in no way related to glacial conditions, and these floods may have occurred at any time during the long interval of mild climate which separated the pre-Kansan glacial stage from the Kansan."

37 Shimek, B., Papers on the Loess, Loess and the Lansing Man, Loess and the Iowan drift: Univ. of Iowa, Lab. of Nat. Hist., Vol. V, pp. 298-381, 1904.

38 Savage, T. E., A Buried Peat Bed in Dodge Township, Union County, Iowa: Iowa Acad. Sci., Proc., Vol. XI, pp. 103-109, 1904.

39 Calvin, Samuel, The Aftonian Gravels and their Relations to the Drift Sheets in the Region about Afton Junction and Thayer: Davenport Acad. Sci., Vol. V, pp. 18-30, 1905.

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

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

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

In discussing the third hypothesis he stated:

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

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

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

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

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

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

Although in the paper to which reference has just been made the judgment of Calvin is very positive with regard to the close relation of the gravels to the pre-Kansan drift, it will be found, if his subsequent papers are read, that he modified his view regarding the origin of the gravels. This change of view was the result not of further field study of the gravels in the Afton Junction-Thayer region, but of some interesting studies by Professor Shimek and himself of gravels in western Iowa and the fossils which they contain. Professor Shimek in the summer of 1908 found fossiliferous sands and gravels in western Iowa, chiefly in Harrison and Monona counties, which he classified as Aftonian gravels of strictly interglacial origin. In a paper in which he described the sands and gravels[40] he discussed their relations to the drifts as follows:

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

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

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

Calvin studied the mammalian remains which were taken from the Aftonian gravels in western Iowa, and in one of his papers[41] he made reference to the gravels and their contained fauna as follows:

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

This same view was emphasized strongly in a paper by Calvin published in 1910.[42] Shimek also presented evidence for the view that the fossiliferous gravel and sand beds of western Iowa are Aftonian.[43] In the first of these papers he introduced the name Loveland for a red joint clay above the Kansan drift in western Iowa which he interpreted to be fluvio-glacial in origin and to have been deposited during the closing stages of the Kansan.

These conclusions with regard to the gravels in western Iowa, and the fauna associated with them, naturally caused Calvin to be less sure than he previously had been regarding his interpretation of the origin of the Aftonian gravels in the Afton Junction, Grand River and Thayer pits of Union county. In his Presidential address[44] read before the Geological Society of America he referred to the gravels of Union county as follows:

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

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

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

43 Shimek, B., Evidence that the Fossiliferous Gravels and Sand Beds of Iowa and Nebraska are Aftonian: Bull. Geol. Soc. of Amer., Vol. 21, pp. 119-140, 1910.
Shimek B., The Pleistocene of Missouri Valley: Science, Vol. XXXI, pp. 75-76, 1910; Geol. of Harrison and Monona Counties: Iowa Geol. Survey, Vol. XX, pp. 277-483, 1910.

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

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

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

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

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

In this paper he referred also to the adequacy of the evidence showing five ice invasions, and pointed out that Iowa was exceptionally favorably located with reference to the known ice movements. He described in considerable detail the pre-Kansan or sub-Aftonian drift, the Kansan drift, the Illinoian drift, the Iowan drift, and the Wisconsin drift; also the interglacial stages separating the glacial stages. In relation to subsequent discussion, it is well to point out that Calvin stated that the Kansan drift could be distinguished from the pre-Kansan drift by physical characters; that forest beds were unknown at any horizon in the region studied by McGee except that between the Kansan and pre-Kansan drifts; that the Yarmouth seems to be the longest of the interglacial intervals, more than equal to all post-Illinoian time; that Illinoian drift of Keewatin origin had not been anywhere recognized; that opportunities for observing the Yarmouth interglacial deposits in natural exposures are fewer than in the case of the Aftonian; that the Iowan is a very young drift compared with the Illinoian; that the amount of weathering of the Iowan must be expressed by a number that is very near to zero; that if differences in the amount of erosion may be taken as a fair measure of the differences in the age of two drift sheets then the Kansan is 100 times as old as the Iowan; that the Peorian interval compared with the Yarmouth or the Sangamon was very short, and that the Iowan is probably not more than twice as old as the Wisconsin.

Introduction of the Name Nebraskan in 1909

The name sub-Aftonian till or pre-Kansan till continued in common use until the year 1909, when Shimek,[44] in relation to his studies in western Iowa and eastern Nebraska, proposed the name Nebraskan for this oldest known drift. Although some of the drift in western Iowa and eastern Nebraska which was included in the Nebraskan by Shimek when the name Nebraskan was suggested for the oldest drift may prove to be Kansan in age, nevertheless, recent studies have shown that pre-Kansan drift extends a distance of more than fifty miles into Nebraska from the east boundary of that state, and hence the name Nebraskan would seem to be an appropriate name for this drift sheet.

Reality of the Iowan Drift Questioned—Calvin's Defense

For some years there was general agreement among the students of the glacial deposits of Iowa and adjacent states that the evidence warranted the interpretation that there were in the Pleistocene period five glacial epochs separated by interglacial epochs. But about the year 1907 some skepticism of this interpretation began to be shown. The reality of the Iowan drift began to be questioned. Leverett[45] in a paper in which he discussed the application of weathering and erosion to the correlation of drifts questioned the existence of the Iowan drift. He expressed the view that the topography of the Iowan area in northeastern Iowa was of the erosional type such as characterizes the Kansan drift but that in northeastern Iowa tabular divides were lacking and none of the drift was fresh. He believed that filling of the valleys by slope wash in the Iowan area accounted for the differences in topography of this area and that of the Kansan of southern Iowa. Leverett's skepticism of the Iowan followed field study in the Iowan area, one of the objects of which study was to determine whether or not the Iowan drift was in reality Illinoian

44 Shimek, B., Aftonian Sand and Gravels in Western Iowa: Bull. Geol. Soc. of Amer., Vol. 20, pp, 399-408, 1909.

45 Leverett, Frank, Weathering and Erosion as Time Measures: Amer. Jour. Sci., Vol. 27, pp. 349-368, 1909.

drift from the Keewatin field. He concluded that the surface material was not different from the weathered Kansan drift and that if any post-Kansan drift was present it was probably of Illinoian age. His views were influenced possibly by his studies of the glacial deposits of Europe. There, only four distinct drift sheets had been established by students of the Pleistocene, and in comparing the American section it was only natural that an earnest effort should be made to analyze and interpret the American deposits in terms of four rather than five glacial drifts. His views were given in a paper[46] in which the North American and European glacial deposits are compared. In referring to the Iowan drift he used the expression "so-called Iowan of the Keewatin field (Illinoian)."

Chamberlin[47] reviewed Leverett's paper. In his review reference is made to Leverett's third glacial stage, which in Germany is Middle Drift, and which is correlated by Leverett with the Illinoian of the Labrador field and doubtfully the "so-called Iowan of the Keewatin field (Illinoian)." Chamberlin stated:

"It is in the grouping of this third stage and in the treatment of the Iowan that there is likely to be awakened the strongest dissent."

He then presented "a few of the salient features of the shifting history of American opinion on the middle drift", which includes the formations which "lie between the Aftonian interglacial beds that cap the lowest till and the base of the declared glacial beds of Wisconsin age." He outlined the history of usage of the terms Kansan and Iowan and suggested that it might be well to apply these terms in the way he applied them originally. With regard to Leverett's suggestion to dismiss the Iowan altogether, as a distinct formation, or else to group it with the Illinoian, Chamberlin stated:

"It is appropriate here to urge restraint, patience, and equipoise, for the distinguishing phenomena, while pronounced and peculiar, are subtle in their gradations and singularly puzzling."

Calvin[48] came to the defense of the Iowan in a paper which did

46 Leverett, Frank, Comparison of North American and European Glacial Deposits: Zeitschrift für Gletscherkunde, B. 4, pp. 241-285, 321-342, 1910.

47 Chamberlin, T. C., Review of Comparison of North American and European Glacial Deposits: Jour. Geol., Vol. XVIII, pp. 470-474, 1910.

48 Calvin, Samuel, The Iowan Drift: Jour. Geol., Vol. XIX, pp. 577-602, 1911.

not appear until after his death. He presented certain facts in explanation of the confusion in the use of the terms Kansan and Iowan. He pointed out that in the earlier discussions of the Pleistocene deposits of northeastern Iowa it was assumed that there were only two drift sheets in that region, named by McGee the Upper Till and the Lower Till and later by Chamberlin the East Iowan and Kansan tills, respectively. Confusion arose when it was discovered that there are three drift sheets and not two only in McGee's area.

''In some cases the upper and middle sheets were described as a unit; in others the lower and middle were treated as one; much more frequently the lowest was ignored, and the descriptions of the 'lower' and 'upper' tills were drawn from the other two. The presence in certain localities of a forest bed or of interglacial gravels, which it was assumed always lay between what the author described as upper and lower tills, as East-Iowan and Kansan, complicated matters still further. There are, indeed, many positive references in the original texts to this forest and gravel horizon—since called Aftonian—as the plane of separation between the two drift sheets at that time credited to the region; but if the texts relating to the subject are carefully read and the maps published in connection with them are examined, it will be seen that the view that the lower till, the Kansan, lies below the Aftonian is untenable. For example, the description of the materials and prevailing color of the upper till on p. 476 of the Eleventh Annual Report is true for only the third of the drift sheets and is at variance with the facts if intended to include the middle till. The same is true of the reference to the large granite bowlders as 'the most conspicuous element of the upper till,' on p. 481. On the other hand, the characteristics assigned to the lower till in the comparisons made between it and the upper on p. 479 are all features that belong to the middle drift sheet; in no true sense are they descriptive of the sub-Aftonian. It is true that at the end of the paragraph there is a reference to the 'forest bed' as a plane of separation between the upper and lower tills, but the characters which the author saw and so correctly and graphically described belong to a super-Aftonian till and to nothing else.''

Moreover, by reference to Chamberlin's chapters in Geikie's Great Ice Age, he showed:

''It is two super-Aftonian tills that are most frequently referred to in the text, and most accurately referred to in the map opposite page 727 as East Iowan and Kansan.''

Calvin quoted Chamberlin's descriptions of the upper and middle drifts as accurate characterizations of the East Iowan and Kansan tills. Furthermore, he pointed out that Chamberlin's mapping is of two super-Aftonian tills, the East Iowan and Kansan. Calvin stated:

"The eastern edge of the Iowan could scarcely be better drawn today. With the exception of a few points which would be mere microscopic dots on a map of this scale, the whole area mapped as Kansan is covered with super-Aftonian till. There is not a single known natural outcrop of sub-Aftonian in the Kansan area east of the Iowan margin. There are no known outcrops of sub-Aftonian in Illinois, Missouri, or northeastern Kansas where the map shows extensive areas of Kansan. It is only very recently that the presence of sub-Aftonian has been demonstrated in Nebraska; but even here it occurs in vertical sections at the base of bluffs, in such position that it could not well be represented on maps of moderate size. In Nebraska, as in practically all the rest of the area mapped as Kansan, it is a super-Aftonian drift that occupies the Kansan area on the map. In all the earlier texts and maps it is a super-Aftonian drift to which the name Kansan was most persistently and most consistently applied."

Calvin then argued for the retention of present usage of the names Kansan and Iowan rather than to make the changes suggested by Chamberlin in his recent paper. Calvin stated:

"The imperfection of knowledge at the time the Iowan and Kansan drifts were named led to confusion and inconsistencies of statements, and these are of such character and extent as to make it now utterly impossible to apply the proposed names in any conceivable way that will be in full accord with all the statements of the texts. The frequent and positive references to the horizon of the gravels and forest beds must be admitted and must be given full weight in determining the particular drift sheets to which the names Kansan and Iowan should be applied. On the other hand, the original descriptions of the lower and upper till—of the Kansan and the Iowan—must have careful consideration, and the evidence of the map in *The Great Ice Age,* above cited, must be taken into account. The descriptions would have to be rewritten and the map redrawn to make them consistent with the view that the Kansan is sub-Aftonian. If the term Kansan is transferred to the sub-Aftonian, and the term Iowan to the drift next above,* practically the whole area represented on the map as Kansan would have to be changed to Iowan. The Iowan would then extend into southern Illinois, would cover southern and western Iowa,

* Some such shift as this seems to be favored by what is said in the Journal of Geology, July-August, 1910, pp. 473-74.

northern Missouri, eastern Nebraska, and northeastern Kansas. With the transfer of the term to the sub-Aftonian the Kansan would be represented on the map by a few dots and thin lines that could be seen only with the magnifier, the whole area comprising an aggregate of only a few sections; and in the present state of knowledge we could not be certain that Kansas has a cubic foot of Kansan (sub-Aftonian) drift. We are face to face with the fact that any application of the terms Kansan and Iowan involves some inconsistencies, is at variance with some of the statements in the original publications; and so long as we seem to need the terms and have to use them, it is only a question of how to use and apply them so as to do least violence to the original maps and descriptions. If the map and descriptive texts referred to may be taken as representing the intent of the authors, the practice of applying the terms which has been followed, and which seems now to come in for a certain amount of mild condemnation, is the only one that is reasonably consistent or possible. For it must be admitted that if the sub-Aftonian is to be called Kansan, and the first super-Aftonian drift is to be the Iowan, more than nine-tenths of the original descriptions are wholly erroneous and misleading, and the map in *The Great Ice Age* showing the distribution of these drifts is altogether meaningless and at variance with the facts. Recent usage in the application of the terms Kansan and Iowan is based on what seemed to be, and still seems to be, the only reasonable interpretation of what the authors had in mind when describing the physical characteristics of the two drift sheets and mapping their areal distribution. A departure from this usage, which would make the sub-Aftonian till Kansan and would apply the term Iowan to the old, weathered till above the Aftonian, with its blue color, its strikingly conspicuous array of greenstones, and with relations to the loess so entirely different from the relations correctly described in the text as pertaining to the Iowan, would necessitate the making of radical and revolutionary changes in the map and descriptive texts above noted. It surely accords better with what was published at the time the names were applied to let recent usage remain unchallenged and unchanged."

Following this discussion with regard to the usage of the terms Kansan and Iowan, Calvin expressed surprise at the attitude taken by Leverett with regard to the Iowan and proceeded to marshal evidence concerning the Iowan drift and its geological relations. The phases of the Iowan presented in detail are as follows: (1) The Iowan drift is. (2) The Iowan drift is young as compared with the Kansan. (3) The Iowan drift is not a phase of the Kansan. (4) The Iowan drift has very intimate relations to certain bodies of loess. (5) The Iowan drift is not related to the Illinoian. Strong evidence is given in support of each of these affirmations.

In regard to the lack of relationship of the Iowan to the Illinoian, Calvin stated:

> "It is scarcely necessary to discuss the suggestion that the Iowan may be correlated with the Illinoian. Parenthetically it may be said that if the Iowan and the Illinoian represent the same stage of glaciation, the name Illinoian becomes a synonym for Iowan, and we shall be reduced to the painful necessity of referring to one of our most beloved drift sheets as the 'so-called Illinoian.' But no such calamity awaits the Illinoian. The Iowan is much the younger of the two. As indicated by the structural and genetic relations above noted, the Iowan—a little later probably than its maximum stage—is practically contemporaneous with the loess; and as the Berlin paper, with noteworthy lucidity, correctly states on p. 299: 'the Sangamon interval separates the loess from the Illinoian stage of glaciation so widely that there would seem to be no relation between loess deposition and Illinoian outwash.' The same long interval, the same wide separation, exists between the Iowan and the Illinoian stages of glaciation. The two drifts are not related in time or in any other way."

Again in 1913 Leverett[49] suggested that the Iowan might be a late substage of the Illinoian with no definite interglacial interval between. In the same year Leighton[50] published two papers which deal with the Iowan. He described an interurban railway cut near Iowa City in which were disturbed weathered gravels between two tills. The gravels were interpreted to be weathered Buchanan gravels which lay on Kansan drift and which had been plowed up by the Iowan ice sheet.

Report on Pleistocene Mammals of Iowa, and Other Papers

A comprehensive report on the Pleistocene mammals of Iowa was prepared by O. P. Hay.[51] The rich faunas of the Aftonian and other deposits of the Pleistocene of Iowa were described fully and illustrated. The inter-relations of the various kinds of life were considered not alone from the standpoint of their distribution

49 Leverett, Frank, Iowan Drift (Abstract): Bull. Geol. Soc. of America, Vol. 24, pp. 698-699, 1913.

50 Leighton, M. M., An Exposure showing post-Kansan Glaciation near Iowa City, Iowa: Jour. Geol., Vol. XXI, pp. 431-435, 1913.
Additional Evidences of post-Kansan Glaciation in Johnson County, Iowa: Iowa Acad. Sci., Proc., Vol. XX, pp. 251-256, 1913.

51 Hay, O. P., The Pleistocene Mammals of Iowa: Iowa Geol. Survey, Vol. XXIII, pp. 1-499, 1914.

and associations in Iowa, but in connection with the Pleistocene of the whole North American continent.

Tilton[52] described some new railway cuts between Des Moines and Allerton. He referred to a gumbo clay on Kansan till which he interpreted to have been formed during the closing phase of the Kansan glacial epoch. He named the gumbo deposits the Dallas formation and correlated it with the Loveland formation, which had been described by Shimek. Tilton earlier published a paper entitled "The Pleistocene Deposits of Warren County, Iowa."

In 1914, Trowbridge[53] stated that he had come to believe as a result of field studies that the entire inner gorge of the Mississippi between Iowa and Wisconsin was later than the earliest drift of eastern Iowa. In another paper[54] he stated that he found no evidence of a pre-Pleistocene Mississippi river valley between Iowa and Wisconsin, and that the Upper Iowa river had cut a valley 600 feet deep during the Aftonian interglacial epoch. He found that pre-Kansan drift was not present in this valley but that the Kansan drift had entered the valley and its tributaries. His views[55] were given more fully in a paper published in 1921. In a paper by Lees[56] there are many interesting facts regarding the Pleistocene deposits of the Des Moines Valley, especially those regarding the relative ages of Des Moines and Mississippi rivers.

Review of the Evidences of the Iowan Stage of Glaciation

As was previously stated, about the year 1907 Leverett began to question the existence of the Iowan drift and to express the view that if there is a drift in northeastern Iowa which is younger than the Kansan drift and older than the Wisconsin drift then this drift should be correlated with the Illinoian drift rather than be interpreted as the product of a distinctly later stage of glaciation than the Illinoian stage. Calvin up to the time of his death in 1911 contended strongly against Leverett's interpretation. He and his associates on the Iowa Geological Survey be-

52 Tilton, J. L., Pleistocene Section from Des Moines south to Allerton: Iowa Acad. Sci., Proc., Vol. XX, pp. 213-220, 1913.

53 Trowbridge, A. C., Preliminary Report on geological work in Northeastern Iowa: Iowa Acad. Sci., Proc., Vol. XXI, pp. 205-209, 1914.

54 Trowbridge, A. C., Physiographic Studies in the Driftless Area (Abstract): Bull. Geol. Soc. Amer., Vol. 26, p. 76, 1915.

55 Trowbridge, A. C., The Erosional History of the Driftless Area: Iowa Univ. Studies, Studies in Natural History, Vol. IX, Number 3, pp. 123-125, 1921.

56 Lees, James H., Physical Features and Geologic History of Des Moines Valley: Iowa Geol. Survey, Vol. XXV, 1914.

lieved the Iowan to be a drift distinct from both the Kansan drift and the Illinoian drift. They mapped the Iowan drift in many counties and were agreed that this drift was the drift which McGee described as his Upper Till. After the death of Calvin in 1911 it seemed highly desirable to have a review of the evidence bearing upon the Iowan problem and hence, with the hope that a satisfactory solution to the question in controversy might be reached, George F. Kay, Calvin's successor as State Geologist of Iowa, asked the United States Geological Survey to undertake the investigation in coöperation with the Iowa Geological Survey. It was agreed that W. C. Alden of the Federal Survey should be assigned to this work and that he should be assisted by M. M. Leighton of the Iowa Survey. Field work was carried forward during two seasons and in the office careful study was given to published and unpublished material related to the Iowan problem. The results of the investigations of Alden and Leighton were published in Volume XXVI of the reports of the Iowa Geological Survey.[57] In the Introduction to this report, page 56, it is stated:

> "It is a pleasure to report that the conclusion has been reached that there is what seems to the writers to be good evidence of the presence of a post-Kansan drift sheet in northeastern Iowa and that this drift appears to be older than the Wisconsin and younger than the Illinoian drift. The writers are, therefore. in the main in agreement with the late State Geologist, Dr. Samuel Calvin, in regard to the Iowan drift. There is, therefore, warrant for continued use of Iowan drift and Iowan stage of glaciation as major subdivisions of the Pleistocene classification."

The chief lines of evidence which caused Alden and Leighton to reach the conclusion that the Iowan drift is a reality and is distinct from other drifts were the following: (1) the topographic character of the Iowan area. It is pointed out that the topography of the Iowan area is not that of normally eroded surfaces like the typical Kansan surface of southern Iowa, but rather it is a drift mantled erosional topography. There are surface irregularities which are the result of glacial deposition rather than differential erosion. Distinct moraines associated with which are kames of fresh gravels are cited. Examples are given of valleys which are cut deep in the Kansan area and which flat-

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

ten out where they head in the Iowan area where cutting is in drift and not in bed rock. The Iowan area as a whole lacks the accordance of upland levels of the tabular divides so characteristic of the erosional Kansan area of southern Iowa. The lack of accordance in the Iowan area seems to be due to unequal mantling by glacial drift, which is confirmed by the presence in many places of relatively fresh drift on gumbotil which can be proved to be Kansan gumbotil. (2) The character of the uppermost till of the Iowan area. It is shown that the degree and depth of oxidation, depth of leaching and other evidences of weathering indicate that the drift of the Iowan area is much younger than the drift of the Kansan area. (3) The gumbotil.[58] Gumbotil is widespread at the top of the Kansan till in southern Iowa where tabular divides are preserved.[59] The topographic position of the Kansan gumbotil is such that it has been possible to trace remnants of it into the Iowan area. And wherever the Kansan gumbotil has been found in the Iowan area it is overlain by a thin mantle of drift which is the Iowan drift. (4) The loess. After having made detailed studies of the loess in the Iowan, Kansan and Illinoian areas, Alden and Leighton reached the following general conclusions—(a) that the deposition of the uppermost till of the Iowan drift area occurred but a short time prior to the accumulation of the main sheet of loess which borders and overlaps it; (b) that the Illinoian till was deposited at a time considerably before this epoch of loess deposition; and (c) that the Kansan drift was deposited considerably earlier than the Illinoian till and much earlier than the loess was formed, or in other words, this line of evidence also supports the view that the Iowan stage of glaciation was distinct from, and later than either the Kansan or Illinoian stages of glaciation.

In connection with the discussion of the age of the Iowan drift, Alden and Leighton presented evidence for their belief that the Iowan drift is a distinct drift from the Illinoian drift. They stated:

"From these various observations it is evident that the Illinoian drift has been modified much more by weathering and erosion than has the

[58] Kay, G. F., Gumbotil, a new term in Pleistocene Geology: Science, N. S., Vol. XLIV, pp. 637-638, 1916.

[59] Kay, G. F., Some Features of the Kansan Drift in Southern Iowa: Bull. Geol. Soc. of America, Vol. 27, pp. 115-117, 1916

Iowan. It also appears that most of the modification occurred prior to the formation of the main deposit of loess. It appears clear therefore that the Iowan drift is entirely distinct from and considerably younger than the Illinoian drift.''

Gumbotil, Its Characteristics, Origin, and Significance

Between the years 1916 and 1922 several papers were published by Kay dealing with the characteristics, origin, and significance of sticky clays or ''gumbos'' which had been described by several geologists as superdrift clays the origin of which had not been explained satisfactorily. These gumbos were studied by Kay first in connection with general studies of the Kansan drift of southern Iowa. He stated:[60]

''(1) The surface of the Kansan drift, after the Kansan ice withdrew, was, according to present evidence, a ground moraine plain, which, from the main divide between the Mississippi and Missouri rivers, sloped gently to the southeast and south toward the Mississippi and to the southwestward toward the Missouri. This drift plain was so situated topographically that weathering agents were very effective, but erosion was slight. As a result of the weathering during an exceedingly long time, a grayish, tenacious, thoroughly leached, and nonlaminated joint clay, which has been named gumbo, was developed to a maximum thickness of more than 20 feet. This gumbo contains only a few pebbles, which are almost wholly siliceous, and grades downward into yellowish and chocolate-colored Kansan drift from 3 to 7 feet in thickness, in many places with numerous pebbles, few, if any, of which are calcareous. This oxidized but noncalcareous drift, in turn, merges into unleached drift, oxidized yellowish for several feet, below which is the normal unleached and unoxidized dark grayish to bluish black Kansan drift. The gumbo is believed to be essentially the result of the thorough chemical weathering of the Kansan drift; but, subordinately, other factors, such as the wind, freezing and thawing, burrowing of animals, slope wash, etcetera, have undoubtedly contributed to its formation. The Kansan drift which has been changed to gumbo may have differed somewhat from the normal Kansan drift that lies below the gumbo.

''(2) After the gumbo plain had been developed by weathering processes on the Kansan drift plain, diastrophic movements seem to have occurred, the plain having been elevated to such an extent that erosion became effective and valleys began to be cut into the gumbo plain. Erosion of the gumbo plain progressed to such an extent that some val-

60 Kay, G. F., Some Features of the Kansan drift of Southern Iowa, Abstract: Bull. Geol. Soc. of America, Vol. 27, pp. 115-117, 1916.

leys were cut to a depth of more than 150 feet before grade was reached and a mature topography was developed. There are now only remnants of the original gumbo plain, the most conspicuous of these being flat, poorly drained areas, known as tabular divides. In places where creep and slumping have occurred the gumbo may be found on slopes at an elevation several feet below the level of the gumbo plain. The tabular divides are more prevalent east of a line drawn north and south through south-central Iowa than west of such a line. In the southwestern part of the State the Kansan gumbo which is *in situ* is found only where the divides, which are no longer distinctly tabular, retain the level of the former gumbo plain."

His later studies[61] revealed a gumbo on the Nebraskan till in Iowa. Many years earlier Leverett had described a gumbo on the Illinoian till which he thought was of the same age as the gumbo on the Kansan but which Kay found to be distinct in age from the gumbo on the Kansan. Kay found that the gumbos on all three tills, the Nebraskan, the Kansan, and the Illinoian, had similar characteristics and had the same relationships to the tills underlying them. He then proposed the name gumbotil for these superdrift clays. He stated:[62]

"Gumbotil is, therefore, a gray to dark colored, thoroughly leached, nonlaminated, deoxidized clay, very sticky, and breaking with a starchlike fracture when wet, very hard and tenacious when dry, and which is chiefly the result of weathering of till. The name is intended to suggest the nature of the material and its origin, and it is thought best to use a simple rather than a compound word. Field work has already established the fact that in Iowa there are three gumbotils, the Nebraskan gumbotil, the Kansan gumbotil, and the Illinoian gumbotil."

In a later paper[63] the characteristics, the origin, and the significance of the gumbotils were discussed fully in relation to extensive field and laboratory studies. In this paper it is stated that there is gumbotil on the Nebraskan, Kansan, and Illinoian tills, but no gumbotil has been developed on the Iowan or Wisconsin tills. The views which had been held by geologists as to the origin of the gumbo clays are outlined. They indicate that there had been great diversity of opinion. A number of sections are described to

61 Kay, G. F., Pleistocene Studies between Manilla, in Crawford County, and Coon Rapids, in Carroll County: Iowa Geol. Survey, Vol. XXVI, pp. 215-231, 1917.

62 Kay, G. F., Gumbotil, a New Term in Pleistocene Geology: Science, New Series, XLIV, 637-638, Nov. 3, 1916.

63 Kay, G. F., and Pearce, J. N., The Origin of Gumbotil: Jour. of Geol., Vol. XXVIII, pp. 89-125, 1920.

show the relations of the gumbotil to the underlying Kansan, Nebraskan and Illinoian tills, respectively. In each case the gumbotil grades downward into leached till and this in turn within a few feet into unleached till. In several cases fresh younger till overlies gumbotil, and in one section this overlying fresh till changes above into leached till and this again into gumbotil, thus repeating the normal succession. Reference is made to the many interesting sections which show disintegrated and decomposed bowlders in the zone between gumbotil and the base of the underlying oxidized and leached till.

The results of a number of pebble counts are given to show that the percentage of siliceous pebbles is considerably higher in the gumbotils than in the leached tills and much higher still than in the unleached tills. Measurements of these pebbles showed also that those from the gumbotils were, on the average, much smaller than those from fresh till and somewhat more rounded.

The discussion of the chemical characters of gumbotil is prefaced by a statement concerning the geo-physico-chemical importance of water and its activity below the surface of the lithosphere. The chemical nature of glacial material and the chemical reactions which transpire in the soil solutions formed during the long period of glacial history are set forth. The chemical products of weathering are classed as crystalloids and colloids, of which the former include the soluble portions, the latter the gluelike, gelatinous, amorphous substances. As a result of weathering of till one should expect to find a gradual relative increase in the proportions of soluble diffusible material from the surface downward, but a gradual decrease in the proportion of alumina; and this is exactly what is found in the analyses of a complete series of strata of glacial till.

Analytical data obtained from the study of samples of gumbotil are tabulated and discussed, and the conclusion is reached "that all gumbotils have a common origin—the chemical modification by weathering of glacial till." In reaching this conclusion cognizance is taken of the decrease downward of the percentage of Al_2O_3 and the pronounced increase of CaO and MgO in the lower horizons. The stages of the alteration processes are outlined, including solution, hydrolysis, the formation of colloids and crystalloids, precipitation and leaching, the gradual passage downward of all the transportable elements of the till, including the iron, the silica, the colloidal clays, and simpler colloidal silicates. The resultant residuum of the chemical leaching process is a practically insoluble stratum—the gumbotil. In addition, such physical factors as wind action, freezing and thawing, and burrowing of ground animals may have played some part.

"The gumbotils, on account of their distinctive characters, wide distribution, and topographic positions, are the most satisfactory criteria that have yet been found for differentiating the older drifts. Furthermore, since the gumbotils are the result of changes which took place in interglacial times, they may be considered in relation to the problem of the relative durations of the interglacial epochs.

"The gumbotils strengthen the view now generally accepted that the Glacial Period involved, not a few thousand but probably hundreds of thousands, and possibly millions of years."

The views of Kay and Pearce on the origin of gumbotil were opposed by Keyes.[64]

The gumbotils have been used in differentiating the Nebraskan till from the Kansan till.[65] Kay's statement is as follows:

"The prevalent opinion among Pleistocene geologists has been that Nebraskan till can be distinguished without difficulty from Kansan till by differences in physical characters of these two tills. Recent detailed investigations of Nebraskan and Kansan tills, where the evidence admits of no doubt as to their correct identification, has shown conclusively that this view must be modified. Many excellent exposures of these two tills, separated by materials which could have been formed only during an interglacial epoch of long duration, have been made available for study in recent years in connection with railway construction and the improvement of the roads of the State. The evidence gained from a study of these exposures in widely distributed areas in Iowa justifies the conclusion that, whereas it is true that in some parts of Iowa the Nebraskan and Kansan tills can be distinguished by their differences in color, texture, structure, lithologic composition, and related features, as was pointed out by Carman in his report on the Pleistocene history of northwestern Iowa, nevertheless there are many areas in Iowa within which these two tills resemble each other so closely that it is impossible to determine by physical characters whether a particular outcrop of till is Nebraskan till

64 Keyes, C. R., Ceramics of gumbo soils: Pan-American Geologist, Vol. XXXVIII, pp. 403-408, 1922.

65 Kay, G. F., Comparative Study of the Nebraskan and Kansan Tills in Iowa: Bull. Geol. Soc. of Amer., Abstract, Vol. 33, p. 115, 1922.

or Kansan till. In such places the only satisfactory basis thus far found in Iowa by which it is possible to decide whether the till is Nebraskan till or Kansan till is the relationship of the till to interglacial material the age of which can be determined. Among the most widespread and most significant of these interglacial materials is gumbotil. If a till is overlain by Nebraskan gumbotil or can be shown to be related to Nebraskan gumbotil, which in Iowa is found as remnants of a former extensive Nebraskan gumbotil plain, the till is Nebraskan till. If, however, the till is overlain by Kansan gumbotil or can be shown to be related to Kansan gumbotil, which also is found as remnants of a former extensive Kansan gumbotil plain, the till is Kansan till."

Recent studies have shown that nowhere does the Kansan gumbotil have a greater thickness than about fifteen feet. It has been found that in some of the sections where it was thought the Kansan gumbotil had a thickness of twenty feet the upper part is an old leached loess and not gumbotil.

Pleistocene Geology of Northwestern Iowa

The glacial deposits of northwestern Iowa have been difficult to interpret. This has been true particularly of the deposits which lie just outside the fairly distinct west boundary of the Des Moines lobe of Wisconsin drift. Those who have studied this area have not been in agreement as to the age and relationships of the tills and associated sands and gravels. The surface drift of this questionable area has been thought by different persons to be of Wisconsin age, to be extra-morainic Wisconsin, to be early Wisconsin, to be Iowan, to be Illinoian, and to be Kansan.

The most comprehensive report on the Pleistocene geology of northwestern Iowa has been prepared by Carman.[66] The field work was begun in 1909, the chief purpose at that time being to retrace in detail the west boundary of the Des Moines lobe of the Wisconsin drift plain. Later, it seemed desirable to revise and correlate the earlier work which had been done outside the Wisconsin glacial boundary. Field work was continued by Carman during the summer of 1910 and parts of the summers of 1911, 1913, and 1916. His studies were carried westward from the Wisconsin boundary to the west boundary of the state and to

66 Carman, J. E., The Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXVI, pp. 239-445, 1917.

some extent into South Dakota to the west and into Minnesota to the north.

In his report Carman gives a summary of the earlier work in northwestern Iowa. Then the several drifts of the region are discussed in order from youngest to oldest. A chapter is devoted to the Wisconsin drift region and a chapter to the area outside the Wisconsin, which Carman interpreted to be Kansan. Two chapters deal with the gravels which are associated closely with the Kansan drift. Another chapter deals with the Nebraskan drift. The two concluding chapters give respectively the geologic history of northwestern Iowa and a summary of conclusions regarding the whole area.

The questionable area just outside the Wisconsin boundary Carman finally mapped and described as Kansan drift. For a time, however, he was of the opinion that there is in this area a drift younger than the distinctive Kansan drift farther west and older than the Peorian loess. He referred to this drift as the drift of the Intermediate area. He even considered giving the name Iowan to this drift. In fact, in his earlier manuscript, submitted to the Iowa Geological Survey in 1913 for publication, this drift was differentiated from the Kansan drift and described in considerable detail. This manuscript was withheld from publication by the Director of the Iowa Geological Survey for the reason that at this time there was doubt in the minds of some geologists as to the existence of an Iowan drift even in the type area of northeastern Iowa. Alden and Leighton had not at this time reviewed the evidences which later convinced them that there was warrant for the continued use of Iowan drift and Iowan stage of glaciation as major subdivisions of the Pleistocene classification. Furthermore, at this time Leverett, as a result of his studies in southwestern Minnesota, which is just north of the area described by Carman, was maintaining that he had not found evidence in his area of a post-Kansan, pre-Peorian drift. He was convinced, however, that he had found in his area a drift younger than the Peorian loess and somewhat older than the Wisconsin drift, that is, an early Wisconsin drift.[67] He believed that this early Wisconsin drift was present also in north-

[67] Leverett, Frank, and Sardeson, F. W., Surface Formations and Agricultural Conditions of the South Half of Minnesota: Minn. Geol. Survey, Bull. 14, pp. 51-52, 1919.

western Iowa. In the hope that the questions in controversy might be settled, several conferences were held in the field in which Carman, Leverett, Kay, and Lees participated. The members of the Iowa Geological Survey were unable to agree with Leverett that there was a drift in the region younger than the Peorian loess and older than the late Wisconsin drift. In 1916 Carman attempted to clear up the matter of the age of the Intermediate area which earlier he had thought had on it a post-Kansan, pre-Peorian drift probably of Iowan age. In his final report he stated:

"A more detailed study of the loesslike clay that overlies the Intermediate area convinced the writer that it is the leached loess and the continuation of the loess of the Kansan region farther west. This correlation of the loesslike clay with the loess makes the area preloess in age. This correlation, coupled with the practical identity of the drifts of the Kansan and the so-called Intermediate areas, and the indefinite boundary separating the two areas, led the writer to reaffirm the interpretation made in 1911, that all of northwestern Iowa west of the Wisconsin boundary belongs to the Kansan drift-sheet. It is believed that the somewhat peculiar topography which exists over the northeast part of the area here called Kansan, and which is not like the typical topography of the Kansan farther southwest, must be explained in some other way than by assuming that it was overridden by another ice sheet which modified the topography but which left no continuous drift sheet."

In referring to the history of the Kansan topography of northwestern Iowa Carman contrasted the conditions in northwest Iowa with those of the Kansan area of southern Iowa. He stated:

"In the Kansan drift region of southern Iowa the principal divides of the 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 fifteen to twenty feet of gray to dark colored, noncalcareous, sticky clay which Professor Kay has called gumbotil and interpreted to be the result chiefly of the chemical weathering of Kansan drift on the level Kansan drift-plain. After the development of the gumbotil zone, 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 few remnants.

"Remnants of the gumbotil zone have been found northward to Carroll and Crawford counties, just south of our region.* The most northerly known outlier of the Kansan gumbotil is exposed in a railway cut 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 Professor Kay. That is, that the Kansan ice-sheet left a relatively even drift-plain; that the gumbotil was 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 and the gumbotil has been destroyed.

"Concerning this matter of erosion of the gumbotil plain in Carroll county, just to the south of our area, Professor Kay says:†

> '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 till 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 some of the evidence, in southern Iowa and in Carroll and Crawford counties just south of our region, upon which Professor Kay bases the gumbotil idea, 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 fifteen to twenty feet over southern Iowa required a very great length of time. Such thicknesses are found northward to Carroll county where a section recorded by Professor Kay from a railway cut three miles west of Templeton shows twenty and one-

* Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Survey, Vol. XXVI, pp. 213-231, 1917.

† Iowa Geol. Surv., Vol. XXVI, p. 218, 1917.

half feet of Kansan gumbotil. It seems very probable therefore 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 altitude of the remnants of the gumbotil along the divide between Mississippi and Missouri rivers increases northward from about 1250 feet at Tingley near the south line of the state to nearly 1500 feet west of Templeton in Carroll county. If these altitudes are used to project the plain northward, it is found that it would pass above all the high points.

"An uplift of the region is postulated in order to cause the erosion of the gumbotil plain. In southern Iowa where remnants of the gumbotil plain exist the postulated uplift rests on firmer basis than for 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 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."

All persons who have studied the Kansan drift of northwestern Iowa have been puzzled to find how free from leaching the till is as compared with the leaching of the Kansan till of southern Iowa. In attempting to explain these differences Carman stated:

"A notable character 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 twenty to thirty 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 unleached.

"In southern Iowa leached till is much more commonly present and in many places has a depth of several feet. It occurs in a zone which directly underlies the gumbotil of the remnants of the upland, where it may be seven to ten feet thick. In such position it grades upward into the gumbotil and represents a less altered phase of the till.

"If a gumbotil zone was formed over the Kansan drift-plain of northwestern Iowa, there was formed also beneath it a zone of leached till, but the erosion which removed every vestige of the gumbotil also removed the leached zone of Kansan till beneath, exposing unleached till everywhere at the surface. This complete erosion of northwestern Iowa below the original plain explains the absence of leached till."

Since the publication of Carman's report on the Pleistocene geology of northwestern Iowa additional field work by Leverett, Carman, and the writer has shown that there is no post-Peorian loess, pre-late Wisconsin drift in the region as Leverett previously had thought, but that there is a drift west of the boundary of the Wisconsin terminal moraine which is post-Kansan, pre-Peorian loess in age. This drift has been differentiated from the Kansan drift chiefly by differences in topography and the presence of weathered loess, silts and gravels which are much younger than the Kansan drift and are older than the drift which underlies the Peorian loess.[68] Leverett, Carman, and Kay are agreed that this post-Kansan, pre-Wisconsin drift in northwestern Iowa probably is of the same age as the post-Kansan drift, the Iowan, of northeastern Iowa.

The Iowan of northwestern Iowa will be described and its boundary discussed in a report now being prepared by Carman.

Pleistocene Geology of Western Iowa

In the year 1924, Kay made the following statements as a result of studies in western Iowa:[69]

"More than a decade ago the Pleistocene tills and associated materials of western Iowa were described in papers published by Udden, Calvin, Shimek, and others. In more recent years nothing has been written about these deposits, although they have been studied to some extent by several persons interested in glacial geology.

"This paper is a result of several weeks of field study, chiefly in Pottawattamie, Harrison, and Monona counties and in adjoining counties farther east. The chief purpose of the investigation has been to deter-

[68] Kay, G. F., Loveland Loess: Post-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. LXVIII, pp. 482-483, Nov. 16, 1928.

[69] Kay, G. F., Recent Studies of the Pleistocene in Western Iowa: (Abstract), Bull. Geol. Soc. of America, Vol. 35, pp. 71-73, 1924.

mine whether or not a restudy of the tills, gravels, and related deposits of the area would permit, in the light of our most recent knowledge of the Pleistocene of southern, southwestern, and northwestern Iowa, a more satisfactory interpretation of the relationships and origins of these glacial materials than was possible when previous studies were made. Considerable additional field work will be necessary before final conclusions can be reached, but thus far the evidence warrants the following tentative statements:

"1. The two oldest known tills, the Nebraskan till and the Kansan till, separated in many places by Nebraskan gumbotil of Aftonian age and in other places by peat, lignite, and soil zones of Aftonian age, have been traced as far west as the western parts of Crawford and Shelby counties, a distance of less than 25 miles from the Missouri river, the western boundary of Iowa. Moreover, in the southeastern part of the town of Council Bluffs, in Pottawattamie county, there is a distinctive zone of leached Nebraskan till separating unleached Nebraskan till below this zone from unleached, oxidized Kansan till above the zone. The evidence in hand seems to indicate clearly that both these old tills extend to the Missouri river and probably, also, beyond into the State of Nebraska. If it were not for the thick deposits of loess overlying the tills in this region, no doubt many additional good sections of these two tills could be seen.

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

"3. The sands and gravels of western Iowa, which were described by Shimek and Calvin as being Aftonian interglacial gravels separating the Nebraskan till from the Kansan till and related in origin neither to deposits made during the closing stages of the Nebraskan glacial epoch nor to deposits made during the Kansan glacial epoch, are thought by the writer not to represent a distinctive stratigraphic horizon separating the Nebraskan till from the Kansan till. But instead they are interpreted as being lenses and irregularly shaped masses of gravels and sands within a single till; or, if in two tills, it is not possible to use the gravels and sands as evidence for differentiating these two tills. The gravels and sands are unleached and appear to be contemporaneous in age with the tills with which they are associated. This view is in accord with the author's interpretation, recently published, of the relationships to till of the well-known gravels near Afton Junction and Thayer, in Union county.

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

"5. The name 'Loveland formation' was given by Shimek to a deposit in western Iowa which is a 'heavy, compact, reddish (especially on exposure to the air) or sometimes yellowish silt, which when dry is hard, with a tendency to break into blocks like a joint clay, and when wet becomes very tough and sticky and hence is sometimes called a gumbo.' The type section of this formation is at Loveland, Harrison county. By early workers this formation was thought to be related to the widespread buff loess of the region, but Shimek believed that it was a fluvio-glacial deposit 'formed during the melting of the Kansan ice.' In many places it is calcareous and contains calcium carbonate concretions, many of which are from three to six inches in diameter; a few were seen with greatest diameter more than 12 inches. The Loveland does not show the laminations of waterlaid clay, but in places sands and silts of distinct aqueous origin are interstratified with the Loveland clay; and in a few places volcanic ash is interbedded with the formation. Moreover, it has the vertical cleavage of loess and stands with similar vertical faces. Although in places fossil shells are present in the Loveland, they are extremely rare in comparison with the numbers of shells which are in the buff loess. The writer believes that the Loveland is not a fluvio-glacial deposit, but a loess distinctly older than the widespread buff loess which overlies the Loveland and which is thought to be chiefly of Peorian age; the Loveland is younger than the Kansan glacial epoch, since it lies upon the maturely eroded surfaces of Kansan till.

"6. Northeast of the village of Little Sioux, in Harrison county, there are along the east slope of the Little Sioux river tills, gravels, and related materials which were described by Shimek as the county-line exposures. Here are fine, whitish 'silts' which were thought by Shimek to be part of a section of sands and gravels which he interpreted as being Aftonian in age. Recently these 'silts' were studied by Doctor Alden, who proved that they are volcanic ash. The writer is convinced that this volcanic ash is not of Aftonian age, but is of the same age as the Loveland loess, with which in some of the county-line exposures it is interstratified."

Additional field work in western Iowa and eastern Nebraska has strengthened the view that both Nebraskan and Kansan drifts were deposited not only to Missouri river but into Nebraska for more than fifty miles.

The exposure in the southeastern part of Council Bluffs which until recently was thought to show unleached Kansan drift overlying leached Nebraskan drift is interpreted now to show unleached till, probably Nebraskan in age, overlying pre-Pleistocene clays, sands and gravels, probably of Tertiary age.

The sands and gravels in western Iowa which were interpreted by Shimek and Calvin to be Aftonian in age chiefly on account of the presence in the gravels of remains of mammals which they believed could have lived only in an interglacial epoch, are thought to be not interglacial but chiefly contemporaneous in age with the till with which the gravels are closely associated, the age of the till being probably Nebraskan but possibly Kansan. Some of the gravels may have been deposited in valleys in the Aftonian interglacial epoch, but their characteristics and their relationships to the till do not seem to support this view. Mammalian remains in the gravels do not of themselves determine whether the gravels are strictly interglacial in age or are of glacial origin, since vertebrate paleontologists are not in agreement regarding the climatic conditions under which mammals such as have been found in these gravels may live. O. P. Hay[70] is of the opinion that the mammals the remains of which have been found in the gravels of western Iowa could not have lived in the immediate vicinity of an ice sheet, but must have lived under interglacial climatic conditions. On the other hand, W. D. Matthew[71] believes that in determining the age of gravels and sands stratigraphic evidence can be more safely followed than fossil evidence. In a letter he stated:

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

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

History of Extinct Lake Calvin, and Other Papers

W. H. Schoewe[72] established beyond a doubt the existence of Lake Calvin. Reference to this lake was made first by J. A. Ud-

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70 Hay, O. P., The Pleistocene of the Middle Region of North America and its vertebrated Animals: Carnegie Institution, Washington, Publication 322A, 1924.

71 Personal communication.

72 Schoewe, W. H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 55-222, 1923.

den.[73] Schoewe described the lake in detail and presented reasons for the belief that Lake Calvin existed for a long time, probably to the time of the Iowan ice invasion. The drainage of the lake was discussed, and the author's view of the origin and history of the lake was presented. The lake covered parts of Muscatine, Cedar, Johnson, Washington, and Louisa counties. Its area was about 325 square miles and in places it had a depth of probably 100 feet.

In several county reports[74] published since 1915 there are interesting facts with regard to the Pleistocene, also in a paper by Cable published in 1921.[75]

Recent Work in the Afton Junction-Thayer Region

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

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73 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, 1898.

74 Geology of Ringgold, Taylor, Clarke, Cass and Adair Counties: Iowa Geol. Survey, Vol. XXVII, 1916; Geology of Lucas and Crawford Counties: Iowa Geol. Survey, Vol. XXXII, 1927.

75 Cable, E. J., Some Phases of the Pleistocene of Iowa, with special reference to the Peorian Interglacial Epoch: privately published, 1921.

Recent studies of the gravels and their relationships to the tills in the Afton Junction-Thayer region justify the statement that the chief gravels of Union county, which were thought by Calvin to have been deposited within the Aftonian interglacial epoch and to constitute a distinct stratigraphic horizon separating the Kansan till from the Nebraskan till, are not of this origin or age. Rather, the chief sands and gravels are lenses and irregularly shaped masses of gravels in the Nebraskan till and contemporaneous in age with that till. They are gravels not of Aftonian age but of Nebraskan age. They lie in large part below the level of the remnants of Nebraskan gumbotil within this area. However, in a few places, as for example, in the Afton Junction pit close to Afton Junction station, the Nebraskan gravels in some places and the Nebraskan till in other places are at the surface of the Nebraskan drift. During the Aftonian interglacial interval the upper part of the Nebraskan till became weathered to Nebraskan gumbotil and the Nebraskan gravels which had a similar topographic relation to the Nebraskan till became weathered to highly oxidized and leached gravels. There are gradations laterally from typical Nebraskan gumbotil to gumboized gravels to thoroughly leached gravels. Later, both Nebraskan gumbotil and the oxidized and leached Nebraskan gravels were overlain by Kansan drift. Some of the Nebraskan gumbotil and some of the weathered gravels were picked up by the Kansan ice and are now inclusions in the Kansan till. Since the Nebraskan gravels which were weathered while at the surface and which now separate the Nebraskan till below from the Kansan till above underwent their great changes during the Aftonian interglacial epoch it may be considered proper to continue to call such gravels Aftonian gravels, but it is here suggested that the name Aftonian gravels be no longer used for the sands and gravels of Nebraskan age which were changed to their present condition in Aftonian time, but that they be called weathered Nebraskan gravels, just as the Nebraskan gumbotil is the name given to weathered Nebraskan till, the weathering having taken place in Aftonian time. The weathered Nebraskan gravels do in places separate Nebraskan till from Kansan till and hence constitute the Aftonian stratigraphic horizon, just as peat does in some places in this area and in other areas. But Nebraskan gumbotil rather than gravels or peat is the most widespread evidence of Aftonian interglacial time in the Afton Junction-Thayer region. This Nebraskan gumbotil has been mapped over wide areas in southwestern Iowa and in other parts of the state and hence is the most significant Aftonian horizon marker which thus far has been found.

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

The Relative Ages of the Iowan and Illinoian Drift Sheets

Sardeson[76] still believes that there is no Iowan drift sheet in northeastern Iowa, and hence contends that only four of the five generally recognized glacial stages should be included in the classification of the Pleistocene.

Frank Leverett in a paper read before the American Philosophical Society[77] stated that he was convinced that there is a post-Kansan drift in northeastern Iowa, the Iowan drift, but suggested that this drift be correlated with a late phase of the Illinoian stage of glaciation. If this were done the classification of American Pleistocene deposits would include four rather than five major glacial stages.

In reaching the judgment that the Iowan stage is related closely in age to the Illinoian stage, Leverett has been much impressed by a pebble band at the surface of the Iowan till and beneath thin loess of Peorian age. He believes that the pebble band was the result chiefly of erosion by running water and that much time was involved in its formation. He is of the opinion that the time between the retreat of the Iowan ice sheet from the Iowan area and the deposition of the overlying loess was comparable to the time between the retreat of the Illinoian ice sheet from southeastern Iowa and the deposition of the widespread loess overly-

76 Sardeson, F. W., Four Stage Glacial Epoch: Pan-American Geologist, Vol. XLVI, pp. 175-188, 1926.

77 Leverett, Frank, The Pleistocene Glacial Stages: Were there more than four?: Proc., American Philosophical Soc., Vol. LXV, Number 2, 1926.

ing the Illinoian drift, which loess is of the same age as that overlying the Iowan drift. Moreover, he stated in his paper that the Iowan drift "lies wholly within the limits of what has been termed the Keewatin field of glaciation." And then, after having presented some facts with regard to the growth of ice sheets, particularly with reference to the Wisconsin ice sheet, he suggested the application of the same principles to the method of growth of the Illinoian ice sheet. He stated:

"It seems but natural that westward growth such as we know affected the Wisconsin ice sheet should also have occurred on the Illinoian and given the ice movement that brought in the Iowan drift."

Here we have his theoretical grounds for suggesting that the Iowan drift should be correlated with the Illinoian.

The questions raised by Leverett with regard to the relations of the Iowan drift to the Illinoian drift called forth three papers by Kay.[78] In the first of these papers he stated that the characteristics, distribution, origin, and age of the deposits of Loveland time in Iowa had been determined.

"The Loveland loess has now been established by stratigraphic methods as being much younger than the Illinoian glacial drift and older than the Iowan glacial drift. The significance of the determination of the definite age of the Loveland loess must be emphasized. It would seem to settle conclusively the relative ages of the Illinoian glacial stage and the Iowan glacial stage. The Loveland loess was deposited after the development over wide areas on the Illinoian till, chiefly by chemical weathering, of a gumbotil more than three feet thick. Furthermore, there was sufficient time after the Loveland loess was laid down for this loess to be leached to a depth of several feet before the coming of the Iowan ice-sheet."

In the paper entitled "Relative Ages of the Iowan and Illinoian Drift Sheets" Kay made brief statements regarding the development of our present knowledge of the Iowan and Illinoian drifts and closely associated glacial and interglacial deposits, following which the arguments of Calvin, Alden and Leighton, and the writer were presented in support of the view that the Iowan

[78] Kay, G. F., Loveland Loess: Post-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. XLVIII, pp. 482-483, November 16, 1928.
The Relative Ages of the Iowan and Illinoian Drift Sheets: American Journal of Science, December, 1928.
Significance of Post-Illinoian, Pre-Iowan Loess: Science, N. S., Vol. LXX, pp. 259, 260, Sept. 13, 1929.

glacial stage was a distinct stage from the Illinoian glacial stage. Kay stated:

"The strongest of several arguments in favor of a long interval between the Illinoian and Iowan glacial stages are the occurrence of a gumbotil on the Illinoian in contrast to no gumbotil on the Iowan, and the leached Loveland loess, which is post-Illinoian gumbotil, pre-Iowan in age.

"The relative ages of the Iowan and Illinoian glacial stages would seem to have been established, and hence five glacial stages and four interglacial stages must continue to be given a place in the classification of the North American glacial deposits."

Widespread Mapping of the Aftonian and Yarmouth Inter-Glacial Horizons in Iowa

For more than ten years members of the Iowa Geological Survey have been mapping the outcrops of Nebraskan and Kansan gumbotils in Iowa. These gumbotils, because of their distinctive characters, topographic positions, and wide distribution, have proved to be the most satisfactory Aftonian and Yarmouth interglacial horizon markers in the state. They have been especially useful in differentiating and mapping the two oldest tills.

Peats and weathered gravels have been and will continue to be of value in interpreting interglacial history, but they have been found to be less serviceable than the gumbotils in areal mapping in Iowa. Only a few good exposures of peat of Aftonian age have been found in the whole state, and these are separated widely from one another. Nor are there many good exposures of peat of Yarmouth age. Moreover, since gravels differ in origin, in topographic position, in degree of weathering, and in other respects, their use in mapping is somewhat restricted. Much less reliance is now placed upon interpretations of gravels and "forest beds" penetrated in well drillings than was given to these materials in the earlier years of Pleistocene studies.

Figure 26 shows the locations of outcrops of Nebraskan gumbotil of Aftonian age separating Nebraskan till from Kansan till in Iowa, and figure 27 shows the locations of outcrops of Kansan gumbotil of Yarmouth age.

A study of figure 26 shows clearly that the Nebraskan gumbotil is widespread in southwestern Iowa; in fact, from these gumbotil outcrops it is now possible to map areally the Nebras-

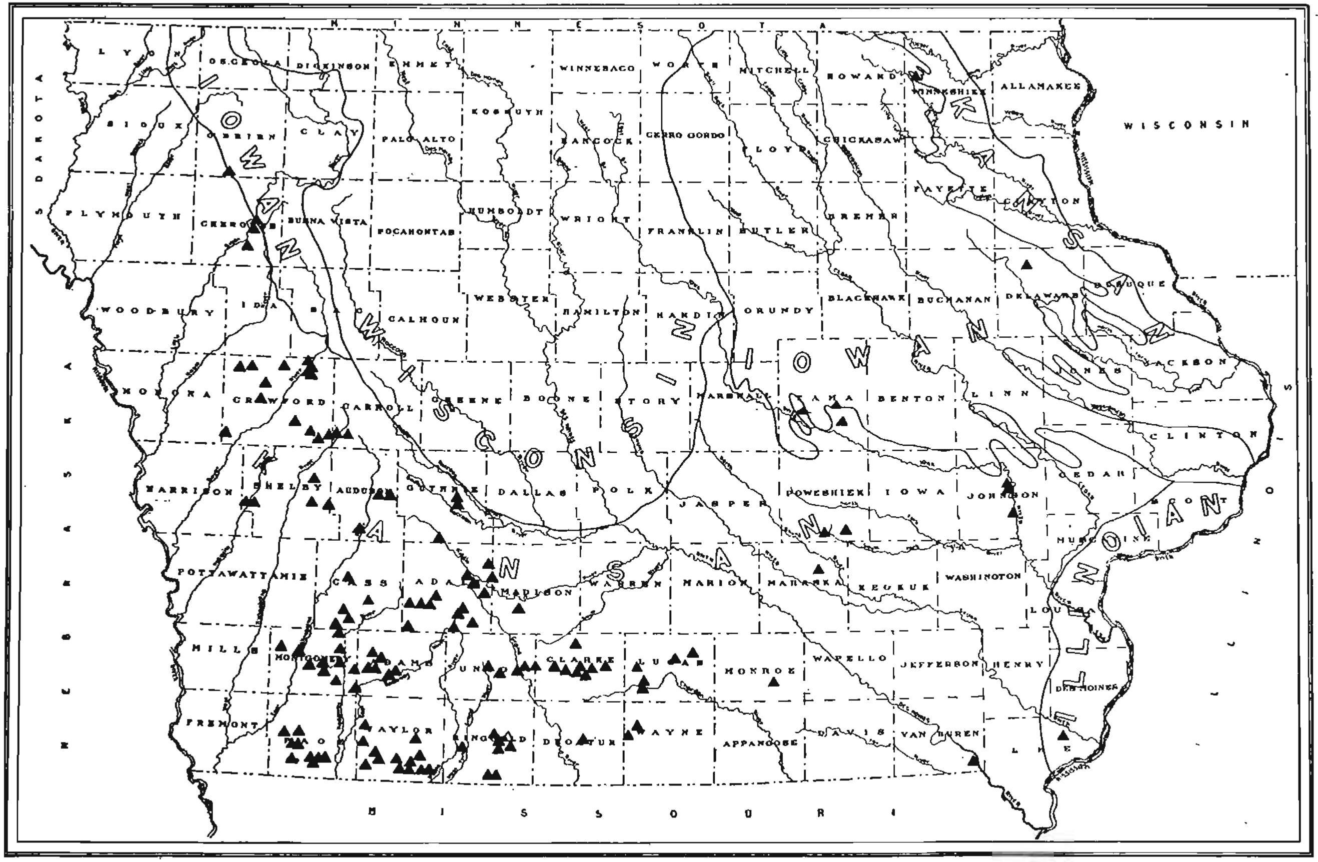

FIG. 26.—The triangles show the locations of Nebraskan gumbotil outcrops in Iowa. This gumbotil is the chief Aftonian interglacial horizon marker in the state.

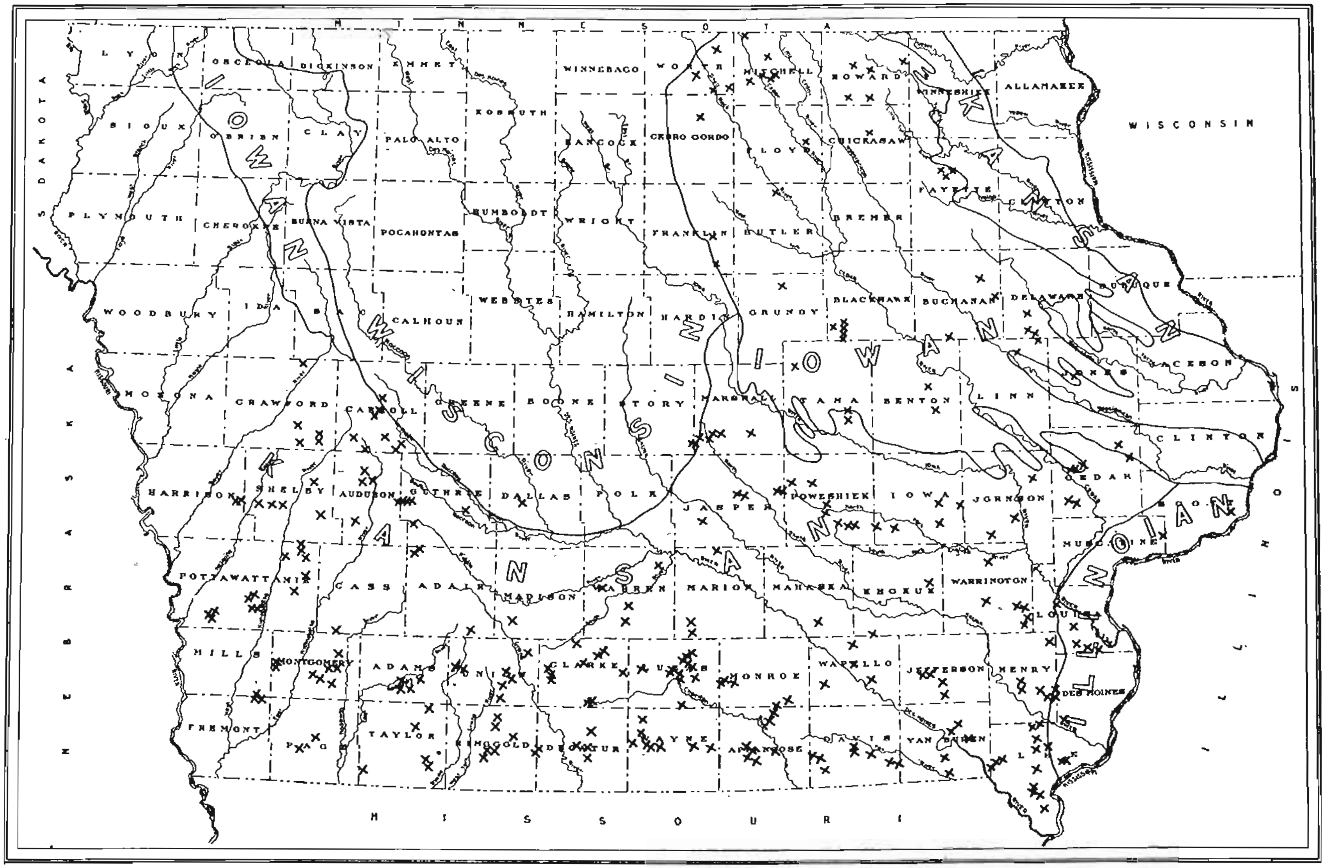

FIG. 27.—The crosses show the locations of Kansan gumbotil outcrops in Iowa. This gumbotil is the chief Yarmouth interglacial horizon marker of the state.

kan drift of this region. This map shows also that Nebraskan gumbotil extends into the northwestern part of the state, and that comparatively few outcrops of this gumbotil have been found within the Iowan area of northeastern Iowa or in southeastern Iowa.

Within the Iowan area of northeastern Iowa, not only are there few known exposures of Nebraskan gumbotil, which represents the Aftonian horizon, but exposures of Aftonian peats and gravels are rare. On the contrary, within this Iowan area, as is shown on figure 27, there are many exposures of Kansan gumbotil, which represents the Yarmouth interglacial horizon. At the surface of several of the Kansan gumbotil exposures within the Iowan area there is a distinct soil zone or "forest bed", above which there is calcareous Iowan drift. Furthermore, at the same topographic position as the Kansan gumbotil, there are in many places thoroughly leached gravels—the upland phase of the Buchanan gravels of Calvin—overlying which in many places there is a thin Iowan drift. From these facts it is now possible to state that within the area of Iowan drift in northeastern Iowa (the area mapped by McGee), the Kansan gumbotil (McGee's gumbo, which he stated was the stratigraphic equivalent of his forest bed) is much better known from observation than the Nebraskan gumbotil or peat separating the Nebraskan till from the Kansan till. In other words, the "forest bed horizon" has been mapped more widely between the Kansan till and Iowan till, that is, between the tills which McGee mapped areally as his Lower and Upper tills, than between the Nebraskan and Kansan tills in this part of the state. It is believed that the Nebraskan gumbotil is at the horizon of the forest bed on Winchell's "older" till of southeastern Minnesota, and that the Kansan gumbotil is at the surface of his "old" till in the same area. McGee's Upper Till in Iowa, the Iowan, was apparently not differentiated in Minnesota by Winchell although it is present there. Nor did McGee map in Iowa Winchell's "older" till.

Both Winchell and McGee had an upper till and a lower till. It is believed that Winchell's upper till or "old" till is the present Kansan till and that his lower till or "older" till is the present Nebraskan till. McGee's Upper Till is the present Iowan till and his Lower Till is the present Kansan till. Together they recognized the three tills which are now known as the Nebraskan, the Kansan, and the Iowan tills. Both of them were familiar also with Winchell's "younger" till, which is the Wisconsin till.

The absence of Kansan gumbotil in northwestern Iowa was explained in a former part of this chapter to be the result of erosion of this gumbotil after it had been developed on Kansan till here as well as in other parts of the state.

The Kansan gumbotil has been found in many places beneath the Illinoian till of southeastern Iowa, and in a few places within the Illinoian drift area Nebraskan gumbotil has been found beneath the Kansan till.

The mapping of the outcrops of Nebraskan gumbotil and Kansan gumbotil has impressed the fact that the original Nebraskan gumbotil plain and the original Kansan gumbotil plain were widespread in the state. It is somewhat surprising to find that so much of each of these plains has escaped erosion. Remnants of the Kansan gumbotil plain are a striking feature of the topography of the Kansan drift area of southern Iowa, where they are known as tabular divides.

Concluding Statements

It is hoped that the history of the investigations and classifications of the Pleistocene deposits of Iowa has been presented in sufficient detail to have enabled the reader to get a clear understanding of the extent to which the glacial and interglacial deposits of Iowa have been studied and of the contributions which have been made by each of the many persons who within the last half century have been interested in unraveling the intricate story of the Pleistocene deposits of Iowa and adjacent states. These investigations and the conclusions drawn from them have attracted attention throughout America and also in foreign lands. In fact, it is now conceded by students of the Pleistocene that Iowa is the area where the records of the glacial and interglacial stages of the Glacial Period have been best preserved and where the deposits, glacial and interglacial, have been best studied in such detail as to permit of their satisfactory interpretation and classification.

Much credit must be given to the pioneers in glacial studies. From their splendid beginnings new facts have been gathered year by year until now there is general agreement that the Glacial Period did not consist of one ice invasion and one retreat, but that there were several major advances of the ice and several major retreats with attendant minor readvances and retreats. All are agreed that the history of each of the glacial and interglacial stages was not simple but complex.

In Iowa the evidence justifies the interpretation that the Pleistocene included five glacial stages and four interglacial stages. In the course of the development of the classification of these glacial and interglacial deposits names were introduced one by one until finally the present classification was evolved. The classification now recognized by the Iowa Geological Survey is as follows:

Glacial stages	*Interglacial stages*
Wisconsin	
	Peorian
Iowan	
	Sangamon
Illinoian	
	Yarmouth
Kansan	
	Aftonian
Nebraskan	

The name Buchanan, which was first used by Calvin, is used still for the interval between the Kansan glacial stage and the Iowan glacial stage. This interval includes the Yarmouth interglacial stage, the Illinoian glacial stage, and the Sangamon interglacial stage.

If all the facts which are now known had been available at the time each of the names was first given a place in this classification it is very probable that more satisfactory terms than are now being used would have been introduced. This paper has given the history of each of the names which now appears in the classification. With the exception of the name Nebraskan, which was used for the first time in 1909, all the names have had their present usage in the classification for more than thirty years. Although adverse criticism can be made with regard to some of the names and to the factors which controlled when the names were introduced, it is doubtful if the advantages which would be gained by attempting to improve the present names would at this time outweigh the disadvantages which would attend the changes made.

The oldest glacial stage in Iowa is the Nebraskan stage. The evidence indicates that the Nebraskan ice sheet covered the whole state, including the so-called "driftless area" of northeastern Iowa. During the Aftonian interglacial stage Nebraskan gumbotil was developed on the Nebraskan till to an average thickness of about eight feet. The second glacial stage is the Kansan. The Kansan ice sheet covered all of Iowa except a small area in the northeast corner of the state. During the Yarmouth interglacial stage Kansan gumbotil was developed on the Kansan till to a maximum thickness of about 15 feet and an average thickness of more than 11 feet. The third glacial stage is the Illinoian. The Illinoian ice sheet invaded only the southeastern part of the state. During the third interglacial stage, the Sangamon stage, a gumbotil was developed on the Illinoian till to a thickness of more than three feet, and later a loess, the Loveland loess, was deposited over the Illinoian gumbotil and older Pleistocene deposits. This loess in places was leached and a soil formed on its surface before the close of Sangamon time. The fourth glacial stage is the Iowan, now well determined in northeastern and northwestern Iowa. The fourth interglacial stage is the Peorian. During this stage the Iowan till was leached to an average depth of less than five feet. Apparently the widespread loess of Peorian age was laid down by wind action very soon after the retreat of the Iowan ice and hence is early Peorian in age. The evidence indicates that the Peorian interglacial stage was by far the shortest of the interglacial stages. The youngest glacial stage is the Wisconsin. In Iowa the Wisconsin glacial lobe terminates at Des Moines.

There seems to be no reasonable doubt, when all the evidence is fairly balanced, that there are in Iowa remains of five distinct glacial stages and of four distinct interglacial stages.

CHAPTER IV

THE NEBRASKAN GLACIAL STAGE

The Nebraskan glacial stage is the oldest of the five glacial stages of the Pleistocene of Iowa. The drift deposited during this stage is known as Nebraskan drift, the name Nebraskan having been given to it by Shimek.[1] Other names which have been used for the drift of the Nebraskan glacial stage are Pre-Kansan, Sub-Aftonian, Albertan and Jerseyan.

Discrimination of the Nebraskan Drift

The Nebraskan drift is exposed in many parts of the state where younger overlying Pleistocene or Recent materials have been eroded. In many places this drift can be identified with certainty only if one can establish definitely its relations to certain interglacial materials the age of which is known.[2] In northeastern Iowa there is an area which a few years ago was included in the Driftless Area, but within which now there are known to be small patches of drift. These patches are so related topographically to Kansan drift that they have been interpreted to be older than the Kansan and hence to be Nebraskan drift. In

[1] Shimek, B., Aftonian Sand and Gravels in Western Iowa: Bull. Geol. Soc. of Amer., Vol. 20, pp. 399-408, 1909.

[2] Kay, G. F., Comparative Study of the Nebraskan and Kansan Tills in Iowa: Bull. Geol. Soc. of Amer., Abstract, Vol. 33, p. 115, 1922.

parts of northwestern Iowa it is possible to differentiate the Nebraskan drift from younger drifts by its lithologic characters as has been shown by Carman.[3]

The base of the Nebraskan till is exposed at only a few places in the state; but from well records it is known at many places. As the Nebraskan drift was, so far as we know, the first glacial material to be deposited over the northern Mississippi Valley area, it lies upon the bedrock surface described in Chapter I. As was stated on page 26 the evidence at present available warrants the interpretation that when the Nebraskan ice sheet invaded Iowa the surface of the bedrock had gentle slopes with a relief of approximately 400 feet. In a few places sands and gravels are known to lie on the bedrock and beneath the Nebraskan till. It is difficult to determine from the records available whether such gravels are or are not a part of the Nebraskan drift.

The upper limit of the Nebraskan drift is its contact with overlying materials. The most prevalent contact is that between the Nebraskan drift and Kansan drift. In fact no exposures of Nebraskan drift in contact with drift other than the Kansan have been recognized in the state except in Delaware county where Iowan drift overlies Nebraskan drift. (See page 154.) In the areas where the younger drifts have been removed from the Nebraskan drift the latter is in many places mantled by loess; where loess is absent, the Nebraskan is overlain only by a soil.

Distribution of the Nebraskan Drift in Iowa

The distribution of Nebraskan drift in Iowa was coextensive with the area of Nebraskan glaciation. In some places there is evidence that all the Nebraskan drift has been removed; in parts of the state there may be areas upon which little if any Nebraskan drift was deposited. From the evidence gained from field studies in all parts of the state, it is known that the Nebraskan ice sheet covered all of Iowa as shown in figure 28.

The Nebraskan drift is now a surface feature in Iowa only in restricted areas as it is nearly everywhere overlain by younger drift or loess. In northeastern Iowa the drift is overlain only by loess as no glacier later than the Nebraskan crossed this area.

[3] Carman, J. E., The Pleistocene Geology of Northwestern Iowa: Iowa Geological Survey, Vol. XXVI, pp. 414-424, 1915.

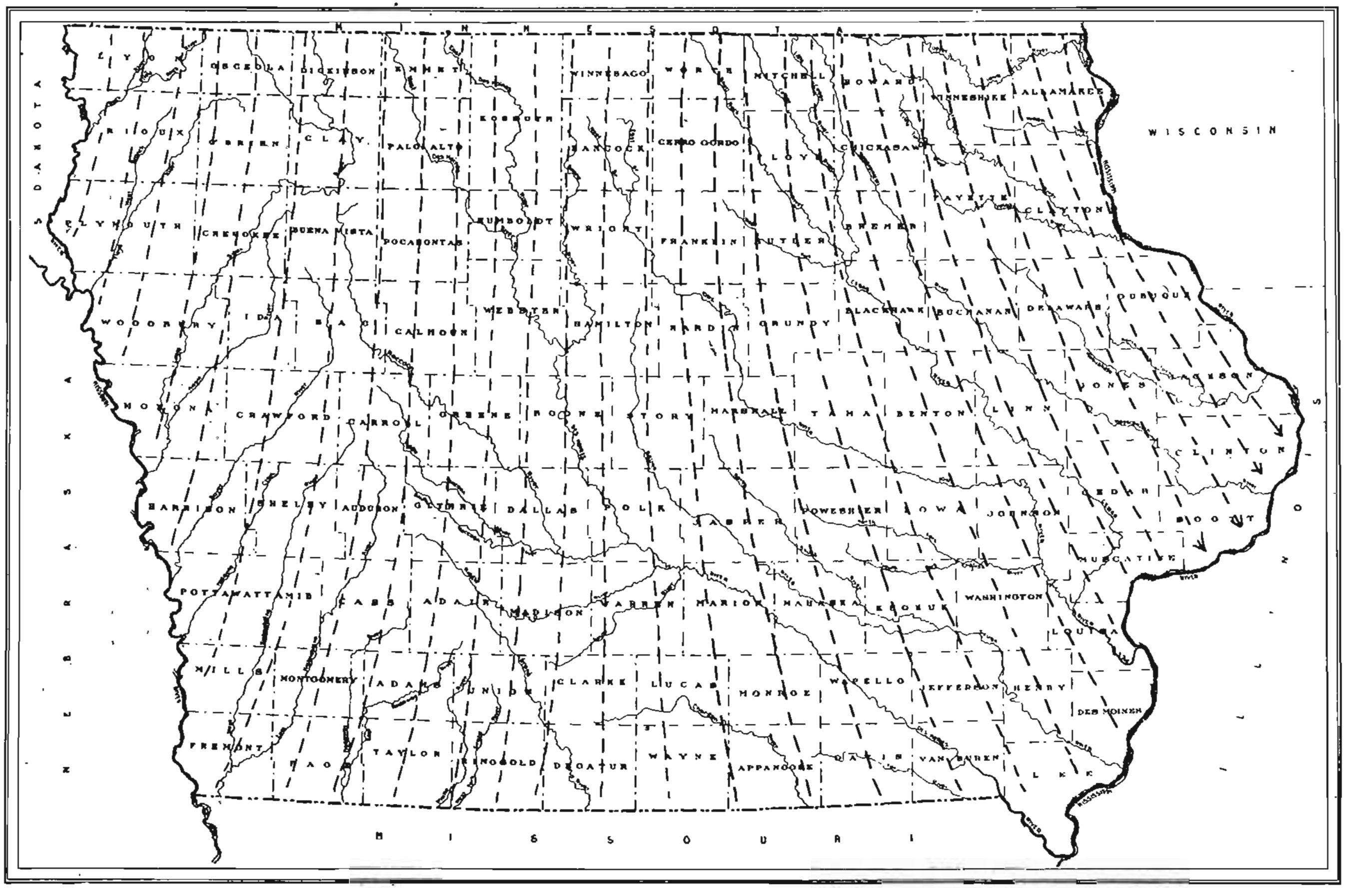

FIG. 28.—Map of Iowa showing the extent of Nebraskan glaciation in the state.

Plate II and figure 32 show the locations of the patches of drift which constitute the representative of the first glaciation in this region.

In some parts of Iowa the erosion of younger drift which overlay the Nebraskan exposed the underlying drift, though in some cases this was to be later covered by loess. The extent of the Nebraskan drift beneath the loess is difficult to determine unless the Nebraskan gumbotil plain is known to have been nearly continuous, in which case the drift below the level of that horizon is largely if not entirely Nebraskan. Valleys of any size cut into the Nebraskan gumbotil plain would have been filled with Kansan drift and later erosion would have caused this drift to be exposed below the level of the Nebraskan gumbotil plain.

The Nebraskan gumbotil surface is known from the outcrops of the gumbotil, and from its manifestations on hillsides as benches, as a spring horizon, and as an infertile soil, to have been extensive in southwestern Iowa at the time of the Kansan glaciation. The distribution of the Nebraskan drift over this area has been mapped, as in Plate II, on the basis of the gumbotil outcrops and the relationship of the Nebraskan gumbotil level to the present topography. Such valleys as were filled with the Kansan drift carry that drift into the area mapped as Nebraskan, but extensive valleys formed by Aftonian erosion were apparently few in the area in which the Nebraskan drift is shown in Plate II.

Origin of the Drift

The Nebraskan drift is typical of material of glacial origin. The great accumulation of ice and snow which resulted in continental glaciation was not uniform in thickness over the land areas, but in certain limited areas there were 'centers of dispersion' out from which the ice tended to move in all directions. Movement did not begin until a great thickness of ice had accumulated and heavy pressure was put upon the land surfaces beneath the ice. A long period of weathering had preceded the formation of the continental glaciers, as a result of which considerable thicknesses of unconsolidated residual and related materials were accumulated on the land areas. The loose products, after the beginning of glaciation, became frozen into the bottom of the ice mass and as this mass moved these materials were pushed along by the pressure of the ice. The rock material which was shoved along and that which was frozen in the ice served as tools which effectively carved, polished, and grooved the glaciated bed. The forward ice movement in the region of erosion removed not only all the accumulated weathered material over wide areas but cut into the unweathered rock as well. The accumulation of material from the different deposits over which the ice passed furnished to the glacier a heterogeneous mixture of weathered and unweathered materials limited in variety only by the different kinds of rock which the ice traversed.

The deposition of the débris which the ice had acquired in its movement over the land took place under conditions which resulted in two distinct types of materials: one of these is an unassorted heterogeneous mass of coarse and fine material—the boulder clay or till due to the melting of the ice with accompanying settling of the whole glacial load in situ; the other is fluvioglacial material—the result of deposition from glacial waters which flowed beneath or on the ice, at the borders of the ice, or out beyond the front of the ice. It consists of assorted clays, silts, sands, and gravels. Some of the fluvioglacial deposits are very well sorted and evenly bedded; in places they are distinctly cross-bedded. The texture of fluvioglacial material is within the range of textures of deposits made by running water with the exception of a few boulders which may well have been rafted into their present positions by ice floating on the water which deposited the sands and gravels. The lithology of the sands and gravels resembles that of the till with which they are associated. In some places the fluvioglacial deposits are poorly sorted and grade both laterally and vertically into sandy and gravelly till and into unsorted till.

The fluvioglacial materials were carried in the streams and other waters related to the continental ice mass, while the ice sheet either was advancing, was in its halting stages, or was retreating. Running water was no doubt active at all times at the margins of the glaciers; the streams flowed at least seasonally upon the surface of the ice, and some waters were active within or at the bottom of the glacier in ice tunnels. From all such waters fluvioglacial materials were deposited.

The origin of the sands and gravels associated with the Nebraskan till and the conditions under which they were deposited are in many places difficult of interpretation owing to the very restricted and often unsatisfactory exposures of these sands and gravels.

As the first continental ice sheet, whose center of dispersion was the Keewatin field, moved over Iowa, it brought a load from the north and added to it from the formations over which it passed in this state. Eventually the time came when the ice at the margin of the glacier melted faster than new supplies were pushed forward by the ice movement. Under such conditions the glacier was in retreat, not by a return movement but by melting. As the ice field occupied successively smaller and smaller areas, more and more of the glaciated bed was left covered with the débris which the ice had not pushed to its farthest front and which it held as its load until melting caused it to be deposited as glacial drift.

The plowing and grinding action of the glacier lowered the hills. The subglacial valleys were depressions into which loaded portions of the ice had moved and stranded while the upper portions of the ice still participated in the ice movement. When the ice had retreated finally from such areas, the old surface bedrock irregularities were no longer to be seen but instead there was a new surface which was a plain with minor surface irregularities and gentle slopes.

Changes in the Drift

Following the retreat of the Nebraskan ice sheet beyond the northern boundary of Iowa and far to the north, Iowa's Aftonian interglacial history began. The new Nebraskan drift surface which resulted from the advance and retreat of the Nebraskan continental ice sheet could not have remained uncovered for more than a very short time. Marginal vegetation undertook almost at once to occupy the new territory, and as soon as the climatic conditions became sufficiently congenial this vegetation no doubt spread rapidly over the surface. Even before the vegetation came wind and rain, sun and frost and other weathering agencies began to alter the newly exposed glacial drift; and these agencies were effective. The air and water oxidized the iron compounds in the drift and changed the color from a drab or gray of the fresh drift to the yellow, red and brown colors of iron oxides. Thus the drift became oxidized. As the oxidation extended downward from the surface other changes followed. The underground water began to dissolve those rock materials which were the most soluble, and as the water passed downward the soluble materials were carried from the soil into the subsoil. Thus limestone and other calcareous materials were leached, first from the surface zones and then from deeper and deeper horizons. Oxidation extended itself downward much more rapidly than did leaching, and hence in the course of time the unchanged fresh till had two zones developed above it—the oxidized unleached zone, and the overlying oxidized and leached zone. But the maximum change had not yet been reached. Vegetation was growing on the surface and the vegetal product of previous seasons was undergoing decay. Organic acids were formed which together with the other agents of weathering brought about additional chemical changes. The result was a reversion to the darker colors of reduced iron compounds; the breaking down of fine materials into still finer—with many of them reduced to colloidal size—and the disintegration and decomposition of many of the minerals of which the drift is composed. This mature product of weathering has been named gumbotil,[4] chiefly a residual product which is very sticky when wet, very hard and tenacious when dry, and which is interpreted to be chiefly the result of chemical weathering of glacial till.[5]

Apparently the formation of the gumbotil caused the rate of leaching to be decreased below that impervious material for whereas the gumbotil on the Nebraskan till has been found to average between eight and nine feet in thickness, the oxidized and leached zone below it is less than three feet thick. Not enough exposures of the oxidized Nebraskan drift have been available for study to warrant any definite statement with regard to the maximum thickness of this oxidized zone, but in places it is more than thirty feet in thickness. The record of the weathering of the Nebraskan till is well preserved in many places because the gumbotil and related materials of Nebraskan drift were covered by the drift of the second ice sheet, the Kansan. In the

[4] Kay, G. F., Gumbotil, A New Term in Pleistocene Geology: Science, N. S., Vol. XLIV, pp. 637-638, 1916.

[5] Kay, G. F., and Pearce, J. N., The Origin of Gumbotil: Journ. of Geol., Vol. XXVIII, pp. 89-125, 1920.

slopes of valleys, in road and railroad cuts and in other excavations which go below the old Nebraskan surface, there are exposures of the Nebraskan gumbotil and underlying zones. Where good drainage conditions resulted from erosion within the gumbotil areas, the gumbotil in places was freed of its colloidal content and there was left an oxidized thoroughly leached secondary gumbotil profile. In places the Nebraskan drift was all eroded before the coming of the Kansan ice sheet; elsewhere the Kansan glacier removed a part of the Nebraskan drift. Under such conditions the upper part of the Nebraskan drift is absent, and where the remaining Nebraskan till is overlain by Kansan till it is difficult in many places to distinguish one from the other. They may be alike in color, texture, lithologic composition and other features.

Typical Sections of the Nebraskan Drift

Some sections of Nebraskan drift from different parts of the state will be described. These sections show the characteristically developed gumbotil, oxidized and leached till, oxidized and unleached till and unoxidized and unleached Nebraskan till. Some sections show the relationships of sands and gravels to the Nebraskan tills. Rarely is an exposure sufficiently deep to reveal in a single section all the phases of the till. In some sections the Kansan till or other material overlying the Nebraskan gumbotil will be described.

NEBRASKAN DRIFT IN SOUTHWESTERN IOWA

In southwestern Iowa there are many outcrops of Nebraskan till overlain by Kansan till. The two tills are separated in many places by Nebraskan gumbotil, in a few places they are separated by leached gravels and in two places at least they are known to be separated by peat. In this part of the state there is a mature erosional topography and the Nebraskan till outcrops only at elevations considerably below the summits of the main divides. One of the best of the known exposures of Nebraskan till in southwestern Iowa is in a road-cut west of the flood-plain of Platte river west of Blockton in Taylor county. The lowest part of the section is seen just west of where the wagon road leaves the flood-plain (Sec. 12, Jefferson Twp., T. 67 N., R. 32 W.). Here the Nebraskan till is unoxidized, unleached boulder clay.

The dry surface of the till is gray to drab in color; the fresh damp surface is dark in color but not distinctly black. The moist till is somewhat flexible and when wet it is sticky. Pebbles and boulders are present, those which were seen ranging up to four feet in greatest diameter. Concretions of calcium carbonate are abundant. A pebble analysis of this Nebraskan till is as follows:

	Per Cent
Limestone	58
Granite	4
Basalt or greenstone	18
Quartzite	7
Quartz	3
Chert	4
Feldspar	1
Dolerite	3
Others	2

Above the unoxidized and unleached Nebraskan till is oxidized, unleached Nebraskan till. In places stringers of this oxidized phase of till extend along joint planes into the unoxidized till. This oxidized till ranges in color from light grayish yellow on a dry surface to brownish yellow on a moist surface. It breaks with an irregular fracture; calcareous concretions are much more abundant than in the underlying unoxidized till. A pebble analysis is as follows:

	Per Cent
Limestone	49
Granite	8
Basalt or greenstone	25
Quartzite	5
Quartz	6
Chert	6
Feldspar	1

This analysis shows that here also limestone is the most abundant constituent.

Above the oxidized, unleached Nebraskan till is oxidized, leached Nebraskan till. This till phase is seen best along the road, particularly just west of the school, in section 10, Jefferson township, where it is only about two feet thick. In color this till ranges from brownish yellow on a dry surface to chocolate color on a fresh damp surface. The presence of disintegrated pebbles and cobbles is a common characteristic and calcareous concretions are abundant. A pebble analysis of the oxidized and leached till is as follows:

	Per Cent
Limestone	0
Granite	23
Basalt or greenstone	26
Quartzite	13
Quartz	16
Chert	12
Dolerite	3
Schist	5
Others	2

This analysis shows that limestone pebbles are absent and that the siliceous content is relatively high. Above the oxidized, leached Nebraskan till is Nebraskan gumbotil.

The Nebraskan gumbotil is a gray to drab colored, thoroughly leached clay, which contains only a few pebbles and these chiefly siliceous. The thickness of the gumbotil in this exposure is about six feet. It is very tenacious when wet and when dry is tough and hard. The presence of calcareous concretions in the gumbotil is a result of precipitation of calcium carbonate which was dissolved and carried downward from overlying till. A pebble analysis of the Nebraskan gumbotil is as follows:

	Per Cent
Limestone	0
Granite	6
Basalt or greenstone	3
Quartzite	20
Quartz	47
Chert	15
Schist	1
Others	8

The analysis shows that this gumbotil has 83 per cent of siliceous pebbles. Above the gumbotil is a gentle slope along which oxidized unleached Kansan drift is exposed.

Southeast of New Market, near the middle of the north boundary of section 5, Mason township (T. 68 N., R. 35 W.), Taylor county, is a fine exposure of Nebraskan gumbotil with Kansan till above it and Nebraskan till below it. The section is as follows:

		Feet
4.	Till, Kansan, oxidized and unleached, many concretions	15
3.	Gumbotil, Nebraskan, gray to drab-colored, leached, a few siliceous pebbles	8
2.	Till, Nebraskan, oxidized, leached	3
1.	Till, Nebraskan, oxidized, unleached, many calcareous concretions; exposed	22

A section in the northeast quarter of section 25, Jackson township (T. 71 N., R. 36 W.), Montgomery county, is as follows:

		Feet
4.	Till, Kansan, oxidized, leached	3
3.	Gumbotil, Nebraskan, gray, few siliceous pebbles, leached	10
2.	Till, Nebraskan, oxidized, unleached, concretions, much jointed	40
1.	Shale at base of slope.	

In Shelby county, in western Iowa, there is a fine section to show Nebraskan gumbotil and Nebraskan till. The road-cut is in the northeast quarter of section 21, Cass township (T. 79 N., R. 40 W.), close to the edge of the flood-plain east of Portsmouth. The section is as follows:

		Feet	Inches
4.	Loess, leached	2	
3.	Till, Kansan, oxidized, unleached, many concretions, irregular jointing	5	6
2.	Gumbotil, Nebraskan, gray, compact when dry; breaks with irregular fracture, leached, siliceous pebbles, few concretions	5	6
1.	Till, Nebraskan, oxidized, irregular fracture, highly calcareous, many concretions	7	

The elevation of the Nebraskan gumbotil is about 1245 feet above sea level. It is of interest to note that less than one mile east of this section at an elevation of 1305 feet above sea level, there is a good section of Kansan gumbotil and underlying Kansan till.

No outcrops of Nebraskan gumbotil have been found between Portsmouth and Missouri river. The loess is so thick in this region that there are comparatively few drift exposures.

A good section to show the field relations of the Nebraskan gumbotil to the underlying Nebraskan till is a railroad cut just east of a viaduct one and one-half miles west of Manning, Carroll county (sec. 18, T. 82 N., R. 36 W.). From the top the cut shows loess, Kansan till, a soil band, Nebraskan gumbotil and Nebraskan till. The section is as follows:

		Feet	Inches
6.	Loess:		
	Leached, yellowish gray on dry surface; yellowish brown to buff-brown on damp surface; no shells or concretions	7	
	Unleached, lighter colored on dry surface than the leached loess, and when damp is buff with gray streaks; contains shells and concretions	5	
5.	Till, Kansan, yellow, unleached, with calcareous concretions; numerous pebbles including granites and quartzites. Below the oxidized, unleached till is gray till with a few pebbles. It is gumbotil-like, but effervesces freely. It was probably picked up from the gumbotil zone below	5	
4.	Soil band, Aftonian, containing carbonaceous material		4
3.	Gumbotil, Nebraskan, gray to drab-colored, few pebbles. The upper 6 feet is fine grained, gray, and is less sticky and gum-		

	botil-like than the lower 7 feet, which is leached but has some calcareous concretions	13
2.	Till, Nebraskan, oxidized, leached but has calcareous concretions upon which are films of manganese dioxide	2
1.	Till, Nebraskan, unleached, oxidized, light yellowish color on dry surface, mottled brownish with gray when damp; many calcareous concretions, especially in upper 10 feet	17

This section was described and chemical analyses of the Nebraskan till phases were reported in a paper by Kay and Pearce on the origin of gumbotil.[6]

On the north and the south slopes of Twelve Mile creek, directly south of Afton, Union county, are fine exposures of Nebraskan gumbotil and Nebraskan till. One of the cuts along the road on the south slope of Twelve Mile creek valley is as follows:

		Feet
6.	Loess, buff-colored, leached	6
5.	Till, Kansan, oxidized, chocolate-colored, leached	4
4.	Till, Kansan, oxidized, unleached, many concretions	21
3.	Gumbotil, Nebraskan, gray to drab color, siliceous pebbles, leached, upper surface uneven owing to ploughing by Kansan..	8
2.	Till, Nebraskan, oxidized, leached	3
1.	Till, Nebraskan, oxidized, unleached, many concretions; exposed	25

The Nebraskan and Kansan tills resemble each other closely in all respects.

A pebble analysis of this Nebraskan gumbotil is as follows:

	Per Cent
Limestone	0
Granite	6
Basalt and greenstone	12
Quartzite	25
Quartz	30
Chert	24
Feldspar	3

Another cut which shows Nebraskan gumbotil and underlying till is along the wagon road west of Osceola, Clarke county, near the school at the southwest corner of section 13, Ward township (T. 72 N., R. 26 W.). The section is as follows:

		Feet	Inches
5.	Loess, gray to light yellow	8	
4.	Till, Kansan, oxidized, leached, ferretto zone on top	5	6
3.	Till, Kansan, oxidized, unleached, many concretions	8	
2.	Gumbotil, Nebraskan, gray to drab-colored, sticky when wet, tough and hard when dry, some calcareous concretions, a few siliceous pebbles; leached	10	
1.	Till, Nebraskan, oxidized, unleached except in narrow upper zone; many calcareous concretions; boulders and pebbles; to base of exposure	25	

[6] Kay, G. F., and Pearce, J. N., The Origin of Gumbotil: Jour. of Geol., Vol. XXVIII, pp. 115-117, 1920.

NEBRASKAN DRIFT IN SOUTHEASTERN IOWA

The exposures of Nebraskan drift in southeastern Iowa are less numerous than those in southwestern Iowa, but the following sections show that drift to be typically represented eastward as far as the Mississippi valley. A road cut near the middle of the east half of section 19, Clay township (T. 69 N., R. 23 W.), Wayne county, shows the following section:

		Feet
4.	Till, Kansan, strongly oxidized, upper part reddish, upper 8 feet leached, many concretions in the unleached till, where thickest	15
3.	Gumbotil, Nebraskan, gray to dark gray, few siliceous pebbles, leached	4
2.	Till, Nebraskan, oxidized, leached	2
1.	Till, Nebraskan, oxidized and unleached	20

In the middle of section 33, Troy township (T. 22 N., R.17 W.), Monroe county, there is a road cut which shows Nebraskan gumbotil underlain by Nebraskan till and overlain by Kansan till. The section is as follows:

		Feet
5.	Loess, leached	8
4.	Till, Kansan, oxidized, leached	5
3.	Till, Kansan, oxidized, unleached	2
2.	Gumbotil, Nebraskan, gray, concretions, few siliceous pebbles, leached	
1.	Till, Nebraskan, poorly exposed along the road	

This cut is 40 feet below the upland and the elevation of the Nebraskan gumbotil is about 925 feet above sea level.

Near the north boundary of section 24, Jackson township (T. 78 N., R. 15 W.), Poweshiek county, on the west side of primary road 59, is an outcrop of Nebraskan gumbotil overlain by Kansan till. The section is as follows:

		Feet
4.	Loess, buff-colored, leached	5
3.	Till, Kansan, oxidized and leached	5
2.	Till, Kansan, oxidized and unleached	8
1.	Gumbotil, Nebraskan, dark gray, leached, few siliceous pebbles, carbonaceous zone at surface; to base of cut	4

The elevation of the Nebraskan gumbotil is about 1018 feet above sea level. The Kansan upland in this region is about 70 feet higher than the Nebraskan gumbotil surface.

In Tama county between two and three miles northeast of Gladstone in section 22, Otter Creek township (T. 83 N., R. 14 W.), there is a cut on the Chicago, Milwaukee, St. Paul and

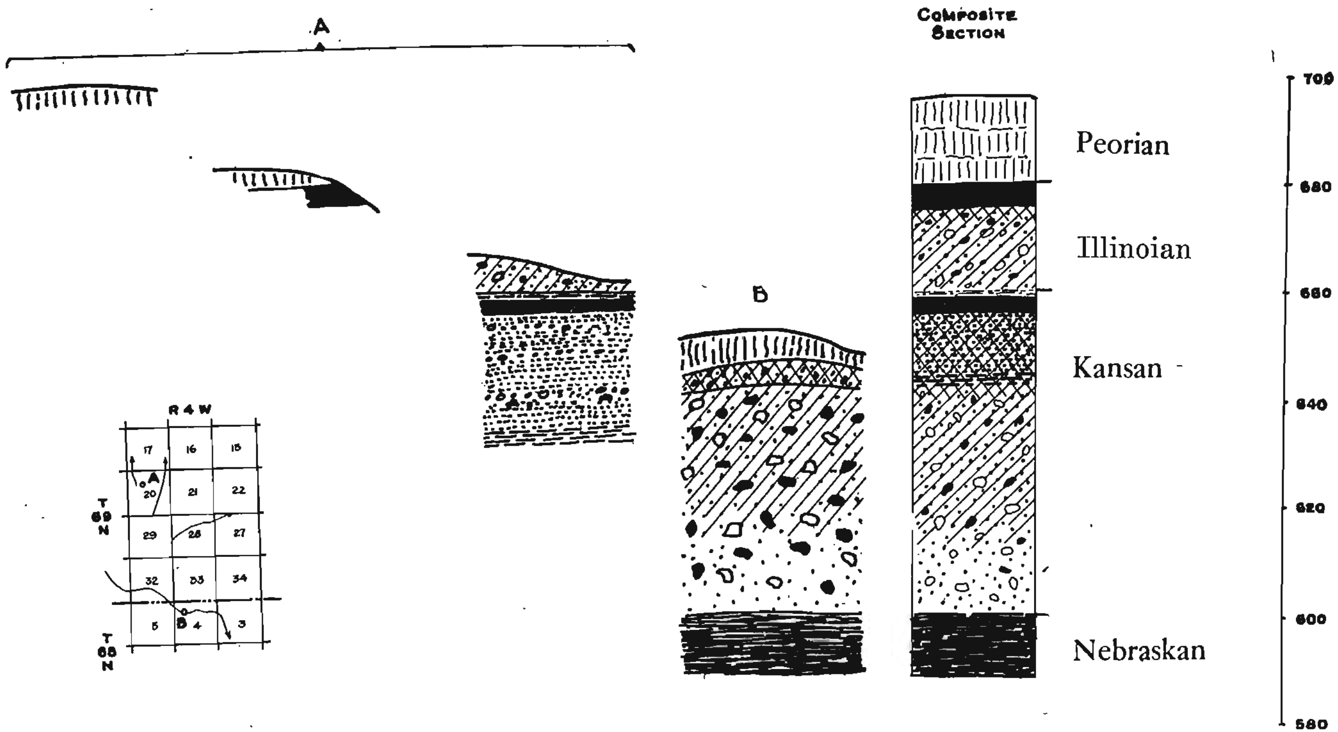

FIG. 29.—Drift sections in Washington and Denmark townships, Lee county.

Pacific railway which shows Nebraskan till and Nebraskan gumbotil. The section is as follows:

		Feet
5.	Loess	5
4.	Till, Kansan, oxidized, leached	5
3.	Till, Kansan, oxidized, unleached, has concretions	4½
2.	Gumbotil, Nebraskan, dense, gray, leached, few siliceous pebbles; upper surface uneven as if disturbed by overriding ice	3 to 5
1.	Till, Nebraskan, oxidized in upper part, in lower part gray to dark slate color, unoxidized, unleached, many concretions; exposed	10

In southeastern Iowa Nebraskan drift has been found with its relationships to the Kansan and Illinoian tills clearly shown. These relationships can be made clear by describing some exposures, (a) in section 20, Denmark township, Lee county, and in section 4, Washington township, Lee county; and (b) in a small valley followed by the Chicago, Burlington & Quincy railroad in sections 28 and 33, Washington township, Lee county. The exposures in section 20, Denmark township, and section 4, Washington township, are about three miles apart. Their locations are indicated at A and B on the small map which is a part of figure 29. Topographically, the upper surface of the A exposure is more than 110 feet higher than the base of the exposure at B. Figure 29 shows graphically the relationships of the tills and related materials as they have been interpreted from a study of the exposures at A and B. The A exposures are in gullies and in the slope of a small valley in section 20, Denmark township (T. 69 N., R. 4 W.), Lee county. The section here is as follows:

2. Loess covering the slopes to an elevation of about 20 feet above the gumbotil on which it lies. The upper surface of the loess is about at the level of the upland plain upon which the village of Denmark is located, and which is approximately 700 feet above sea level.
1. Gumbotil, Illinoian, typical bluish gray color, few siliceous pebbles, irregular polyhedral fracture, about 3 feet thick.

About 150 yards to the southwest of this gully exposure is an exposure lower topographically and showing the following:

		Feet
3.	Till, Illinoian, oxidized, highly calcareous. From this outcrop the Illinoian gumbotil and loess have been eroded	7
2.	Till, Kansan, gumbotil-like, more strongly oxidized than the till above. Much carbonaceous material in the upper 1 foot; leached, but having some secondary calcium carbonate as concretions and in joints; about 4 feet thick but grades horizontally and vertically into sands and gravels, strongly oxidized red-	

	dish and brownish, highly ferruginous, strongly cemented and thoroughly leached	22
1.	Silts, blue-black, leached	1½

Farther down the valley the Kansan till is exposed; also in road cuts below the Illinoian till between Denmark and the B exposures next to be described. The B exposures are in the slopes along Lost creek east of the road crossing in section 4, Washington township (T. 68 N., R. 4 W.), Lee county. The following section was taken in a high bluff on the east bank of Lost creek:

		Feet
6.	Loess, light buff in color	5½
5.	Pebble band, a concentration of the larger material in the drift; formed during erosion. A few inches.	
4.	Till, Kansan, oxidized brownish and yellowish, leached	5
3.	Till, Kansan, oxidized and unleached. Upper part has a zone of concretions which marks the base of the overlying leached till; sand masses included in the till; oxidized till grades downward into unoxidized and unleached till	22
2.	Till, Kansan, unoxidized and unleached, very dark when moist, light gray on a dry surface, hard, tough, difficult to cut. Many joint planes along which oxidation has taken place	20
1.	Till, Nebraskan, oxidized, leached, distinctly reddish on surface but greenish gray when freshly cut. The color is in striking contrast with the unoxidized and unleached till above; breaks into small irregular fragments; compact and uniform throughout its thickness, nonlaminated, more sandy near the base	11

The Nebraskan in this section is interpreted to have been Nebraskan gumbotil from which much of the colloidal material was carried while the Nebraskan gumbotil plain was being eroded and before the advance of the Kansan ice sheet; the elevation of the surface of the leached Nebraskan till is about 600 feet above sea level. A study of figure 29 will show that in this area the thickness of the Kansan till is approximately 60 feet, of the Illinoian till 20 feet, and of the loess less than 20 feet.

Another section in southeastern Iowa which shows Nebraskan drift is in a small valley followed by the Chicago, Burlington & Quincy railroad. The upper part of the section is near the middle of the southwest quarter of section 28, Washington township (T. 68 N., R. 4 W.), Lee county; the lower part of the section is in two exposures in the northern part of section 33 of the same township.

The upper part of the section located in section 28 is as follows, where the upland is a few feet above the top of the exposure and is underlain by loess:

	Feet	Inches
6. Gumbotil, Illinoian. A band along the brow of the cut, which is a few feet below the upland. The gumbotil is gray to ashen on a dry surface. On a damp surface it is dark gray mottled with brown. It has the starchy fracture which results in polyhedral blocks of small size. It is leached and contains siliceous pebbles, also a few secondary calcium carbonate concretions	4	6
5. Till, Illinoian, oxidized and leached; the prevailing color is brownish buff grading upward into gray through a narrow zone in which the colors are blended; some pebbles, cobbles and boulders; no concretions	5	6
4. Till, Illinoian, oxidized and unleached; buff to brown with very few patches of gray; jointed; breaks into irregular fragments a few centimeters on a side; larger fragments as well as pebbles in this zone; about	1	
3. Gumbotil, Kansan; dark gray to drab in the upper part, lighter color in the lower part; some patches of brown; starchy fracture; closely spaced joints in upper part, becoming more widely spaced in lower part, but the resulting fragments in each case are the irregular, many-sided blocks a few millimeters in diameter; leached; a few secondary concretions of calcium carbonate; calcareous zone around the concretions usually very narrow	8	6
2. Till, Kansan, oxidized and leached; the gray of the gumbotil found in patches through this otherwise brownish buff clay	5	
1. Till, Kansan, oxidized and unleached; yellowish brown in color; jointed, breaks into blocks the surfaces of which are in many cases of somewhat darker color than the face of the cut; unleached; has concretions especially in the upper part	12	

About one-fourth mile down the gully from the section just described there is east of the railroad track an exposure about 60 feet in depth on the face of a truncated spur on the valley wall. Here is the following section:

	Feet
4. Loess, buff-colored, leached, upper surface below the upland level	3
3. Till, Illinoian, oxidized, unleached	8
2. Gumbotil, Kansan, a distinct dark zone extending across the face of the exposure; thoroughly leached, few siliceous pebbles	12
1. Till, Kansan, oxidized and unleached except in upper part, concretions; to the base of the cut	37

About 400 yards still farther down the valley is a tributary gulch from the west. Here is exposed the transition zone between the oxidized and unleached Kansan till and the unoxidized and unleached Kansan till, which is here about 15 feet thick. Near the base of the unleached and unoxidized Kansan till there is much carbonaceous material, beneath which is a zone a few feet thick of leached sands and silts, the upper part of which is very carbonaceous. Included in the sands and silts are sticks and logs, some of which have a diameter of nearly six inches. The leached sands and silts, which are interpreted to be Aftonian in age, are in marked contrast to the overlying unleached carbonaceous Kansan till. Beneath the Aftonian leached sands and silts there is unoxidized and unleached till which is interpreted to be Nebraskan till. The elevation of the Aftonian horizon is 600 feet above sea level, which is the elevation of the upper surface of the Nebraskan till described from section 4, Washington township. Moreover, from the top of the Nebraskan till in section 33, Washington township, to the surface of the Illinoian gumbotil in section 28, Washington township, there is a difference in elevation of approximately 80 feet; the thicknesses of the Kansan and Illinoian tills in these sections are similar to the thicknesses of the Kansan and Illinoian tills in the sections in section 4, Washington township, and section 20, Denmark township.

The relationships of the Nebraskan till to the Kansan and Illinoian tills in sections 28 and 33, Washington township, are shown in figure 30.

In Johnson county there are several exposures of Nebraskan till and related materials. One of these is on primary road 161, on the north slope of Indian Lookout in section 33, Lucas township (T. 79 N., R. 6 W.). Here is Nebraskan gumbotil underlain by Nebraskan oxidized and leached till below which is oxidized and unleached Nebraskan till. Above the gumbotil is Kansan till above which is thick loess. The elevation of the Nebraskan gumbotil is approximately 700 feet. To the west of the road is a spring where the Nebraskan gumbotil again outcrops; still farther west and at the same elevation the Nebraskan gumbotil is seen.

Another most interesting exposure in Johnson county is in the interurban cut just west of Iowa river at Iowa City. Here in the base of the cut is bluish black till containing many striated limestone pebbles. The till is highly calcareous and above it are highly oxidized, distinctly reddish leached gravels about eight feet thick. Similar gravels have been found also in excavations for the basements of buildings on the east side of Iowa river at the same elevation, namely, about 710 feet above sea level. The Nebraskan till here is thin; it lies on Devonian limestone. Above the leached ferruginous gravels which are exposed on the south side of the cut for nearly 200 yards there is thick loess. On the north side of the cut the Peorian loess is 22 feet thick, the upper

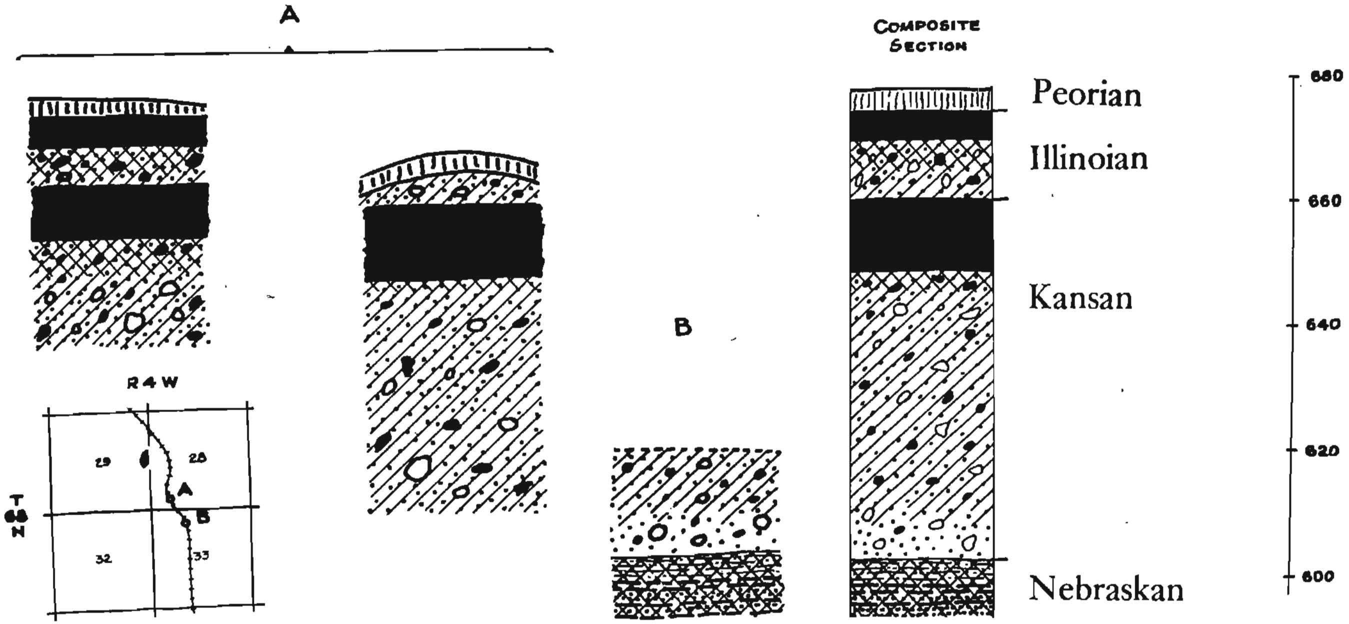

FIG. 30.—Drift sections in Washington township, Lee county.

15 feet being leached and the lower 7 feet unleached. Beneath the Peorian loess is thin, leached Loveland loess. The gravels are interpreted to have been deposited by the Nebraskan ice sheet, and hence to be Nebraskan gravels. Figure 31 shows the Nebraskan till and gravels and overlying loess. To the southwest of this interurban cut is an exposure at approximately the same elevation, in the southeast quarter of the northeast quarter of section 8, Lucas township, Johnson county. This is in the south part of the Finkbine golf field, in a ravine about 100 yards north of the

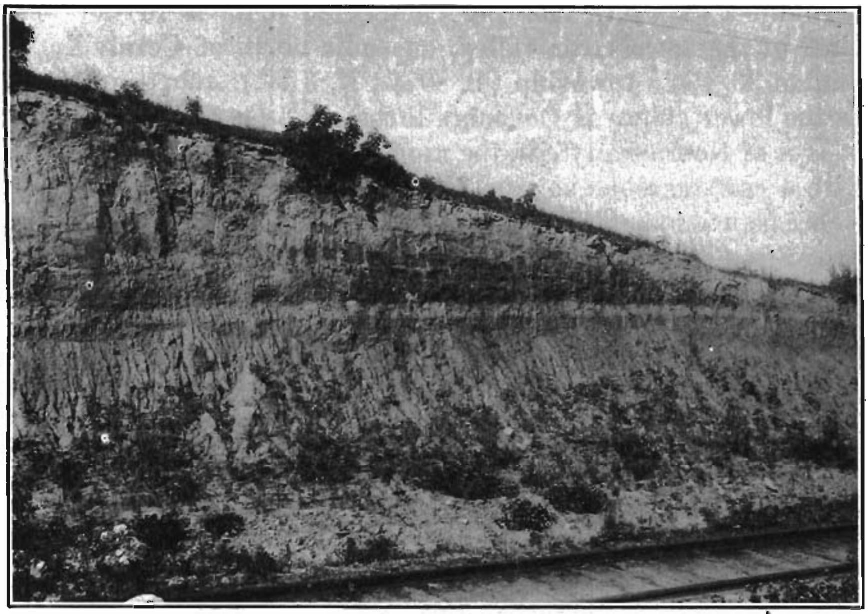

FIG. 31.—Intururban cut west of Iowa river at Iowa City. Shows loess, Nebraskan gravels, and Nebraskan till.

Rock Island railroad tracks. Here are highly oxidized, leached gravels and sands exposed for a depth of 15 feet, 6 inches. The upper 5 feet of the deposit is gravel and gumbotil-like till, above which is 7 feet of leached loess. Less than one mile from this exposure is the University of Iowa new football stadium. When the excavations for this stadium were being made Nebraskan gumbotil and related materials overlain by two loesses were made available for study. The Nebraskan gumbotil in the floor of the stadium is intimately associated with thoroughly leached Nebraskan sands and gravels. The base of these deposits was not reached in the trenches which were dug four feet deep below the floor of the stadium. In the south slope of the stadium the following section was exposed:

		Feet
5.	Loess, Peorian, buff-colored, leached to top of slope	10
4.	Loess, Peorian, buff color, iron tubules, calcareous, contains shells, grades into 3 below	2
3.	Loess, Peorian, gray, many iron tubules, calcareous, many shells	8
2.	Loess, Loveland, oxidized reddish, leached, compact, contains carbonaceous specks and flakes, no pebbles	2
1.	Gumbotil, Nebraskan, drab to dark gray to purplish color, tough, leached, few siliceous pebbles, to base of slope	6

Another exposure showing Nebraskan drift is in the west bluff of the Iowa river valley, one mile north of Coralville, in section 33, Penn township (T. 80 N., R. 6 W.), Johnson county. In the lower slopes is Devonian limestone. On the limestone is 16 feet of Nebraskan drift, the upper 5 feet of which is gumbotil with a carbonaceous zone at its surface. The elevation of the Nebraskan gumbotil is about the same as the elevation of the Nebraskan drift in the interurban cut, in the Finkbine field cut, in the University stadium, and in the slope at Indian Lookout. Above the Nebraskan gumbotil in the Coralville exposure is Kansan drift, oxidized and unleached, with an exposed thickness of 25 feet and overlain by loess.

NEBRASKAN DRIFT IN NORTHEASTERN IOWA

In northeastern Iowa three outcrops have been found thus far which have been interpreted as showing Nebraskan gumbotil. Two of these are in Delaware county, the other is in Winneshiek county. One of the exposures in Delaware county is about one mile north of Thorpe station, between sections 28 and 29, Honey creek township (T. 90 N., R. 5 W.). Here is what is interpreted to be Nebraskan gumbotil lying on the bedrock and overlain by till. The other exposure in Delaware county is about 2 1/2 miles south of Thorpe station, in the northeast corner of section 17, Delaware township (T. 89 N., R. 5 W.). Here in a shallow road cut is exposed one foot of dark gray Nebraskan gumbotil overlain by about 5 feet of oxidized, leached Iowan till. At approximately the same elevation as the Nebraskan gumbotil and about one-eighth mile farther south is a pit in highly oxidized Nebraskan gravels, which are leached to the bottom of the 11 feet of the exposure. The gumbotil and gravels are about 40 feet lower than the known exposures of Kansan gumbotil in this area. The exposure in Winneshiek county is in the middle of the south line of section 10, Lincoln township (T. 98 N., R. 10 W.).

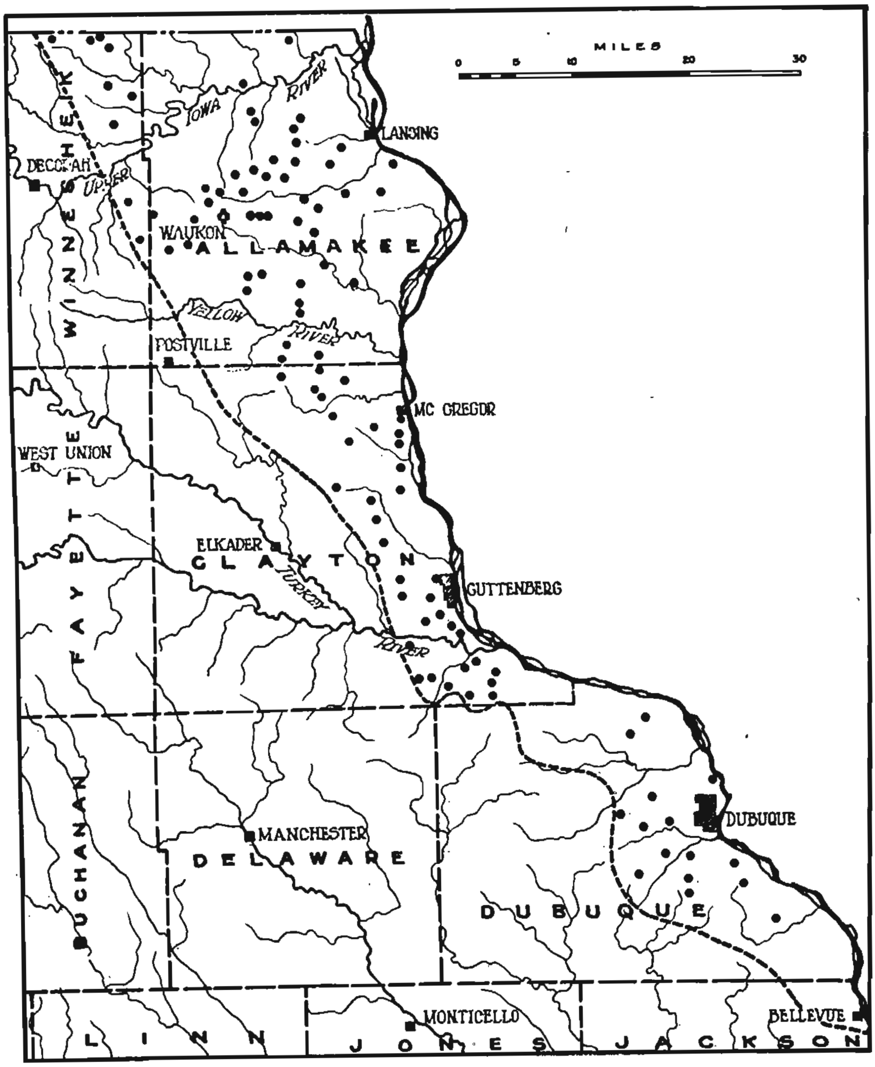

FIG. 32.—Northeastern Iowa, showing by dashed line the margin of the Kansan drift and by dots the locations of drift patches in the region formerly included in the Driftless Area.

Here is Nebraskan gumbotil overlain by about three feet of Kansan till. Its elevation is about 1,050 feet above sea level.

Nebraskan drift has been recognized in the extreme northeastern part of Iowa as the only drift there present. Its identification is based on its topographic position in relation to known younger drifts, including the Kansan, Illinoian, and Iowan. Trowbridge, Williams, and others have shown that the northeast corner of Iowa, formerly included in the Driftless Area, is not entirely driftless. It is, however, an area in which only patches of drift are found. Figure 32 shows some of the localities in which the drift has been found.[4] The topographic position of the drift patches in relation to the topography of the region indicates considerable erosion since the deposition of the drift. The area within which there are patches of thin drift includes some 1400 or 1500 square miles bordering Mississippi river from the northern boundary of the state to the latitude of Bellevue in Jackson county. Within this region there are three levels of erosion represented on the present surface, and a fourth level is buried beneath silts which occupy the floors of the present valleys. The region therefore is divided into: somewhat flat uplands representing, according to Williams, old erosion surfaces, which occupy about 140 square miles of the area; the flats along the present drainage levels, which cover about 210 square miles; and the slopes between the various levels, which account for the remaining 1090 square miles of the area. The region is in maturity with the maximum area in slopes and in the stage of transition between upland flats and large valley flats.

As was stated in Chapter II the upland areas show two levels of erosion about 200 feet apart vertically. The higher of these levels has been called the Dodgeville peneplain and the lower the Lancaster peneplain. The present drainage, where reduced by the larger streams to a low gradient, lies some 300 to 400 feet below the Lancaster peneplain. Beneath the beds of the larger streams, and also under some of the channels of the smaller streams, are rock gorges cut to a depth of 180 feet below the present stream levels and filled to these levels with stream débris. There are thus recognized four levels of erosion three of which are significant features of the present surface. Nebraskan drift is limited in its distribution to the surface of the two high peneplains, the Dodgeville and Lancaster peneplains, or to the slopes between these surfaces. Extensive field studies have failed to reveal within this so-called "Driftless Area" any drift at elevations lower than the surface of the Lancaster peneplain. How-

[4] Map from unpublished manuscript by A. J. Williams, Library, State University of Iowa. 1923.

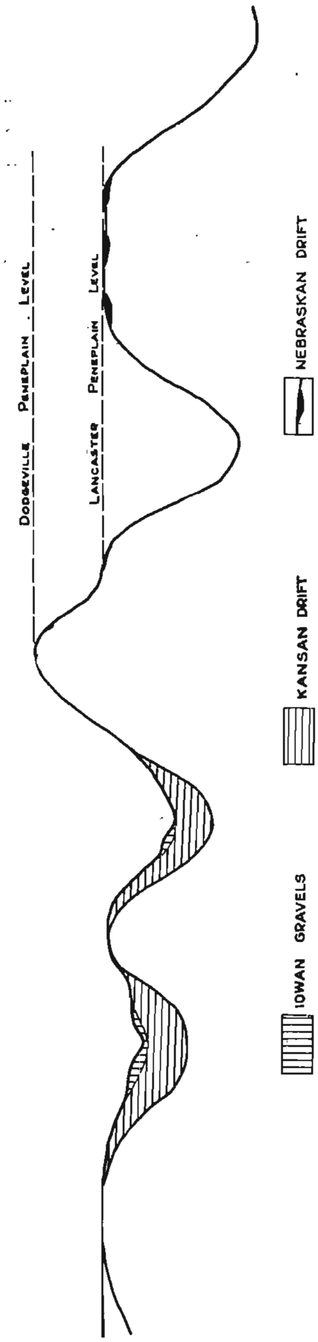

FIG. 33.—Relationships between the Dodgeville and Lancaster peneplains and the glacial drifts of various ages, shown diagrammatically.

ever, at the west edge of this area there is drift which extends down into the inner and deeper valleys below the level of the Lancaster peneplain. This drift is of Kansan age. The later erosion valleys which have been cut into and in places through this drift have in many places terraces of relatively fresh materials, which now lie ten to thirty feet above the present streams. These terraces are regarded by Alden and Leighton[7] as probably Iowan in age. Figure 33 is a diagrammatical illustration of the relationships between the Dodgeville and Lancaster peneplains and the drifts of various ages.

NEBRASKAN DRIFT IN NORTHWESTERN IOWA

The Nebraskan till of northwestern Iowa has been described by Carman in his paper entitled "Pleistocene Geology of Northwestern Iowa".[8] In places in this part of the state the Nebraskan till differs in its characteristics from that till in other parts of the state, and moreover, it can be distinguished from the Kansan till by lithological, textural, and other characters.

The exposures of Nebraskan till in northwestern Iowa are chiefly within the valley of Little Sioux river in Cherokee county. Here the river has cut through the Kansan till into the Nebraskan till.

[7] Alden, W. C., and Leighton, M. M., The Iowan Drift: Iowa Geological Survey, Vol. XXVI, pp. 130-137.

[8] Carman, J. E., The Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Ann. Report, 1915, Vol. XXVI, pp. 239-445, 1917.

Parts of the Nebraskan ice sheet had as the most important sources of material the shales of Cretaceous age which covered eastern North and South Dakota, western Minnesota, and western Iowa. This source explains the very compact, somewhat calcareous clay which characterizes some of the Nebraskan till of this part of the state. Carman[9] states that the Nebraskan till of Cherokee county

"is gray modified by various tints of chocolate brown, purple and blue. The most important colors are chocolate, gray and purplish gray, and generally the color is darker with greater depth beneath the face of the exposure. In its most weathered phase it has a yellowish cast. The till is almost free from pebbles or sand grains, and is so fine-grained that in most cases very little grit can be detected even when a small piece is tested between the teeth. The matrix of the till is commonly calcareous but at some places it is only slightly so or even is entirely free from calcareous material, although it is the fresh unaltered till. Calcareous concretions ranging in size from small grains to masses eight or ten inches across are found in the upper part of this till in some of the exposures. The till is compact and tough when fresh, but in most surface exposures it is loose, and can be dug easily with the hammer. It has a peculiar and characteristic method of fracture by which it breaks up into small angular fragments similar to those into which starch fractures on drying."

It is difficult to distinguish the Nebraskan gumbotil of the Cherokee region from the Nebraskan till. This gumbotil in other parts of the state is gray to drab in color, is tough, is noncalcareous, and has few pebbles. In many places in Cherokee county the fresh Nebraskan till has similar characteristics, and moreover, it does not oxidize to give the yellow-brown colors as do the Nebraskan tills farther south. However, if a careful study of a section shows that the upper part has only siliceous pebbles and has only secondary calcium carbonate, whereas, lower in the section the clay has not only secondary calcium carbonate but some pebbles of limestone, one is justified in reaching the judgment that the upper part is weathered to Nebraskan gumbotil, whereas the till with the limestone pebbles is fresh Nebraskan till. A good exposure in which there is Nebraskan gumbotil underlain by Nebraskan till is in the lower part of the east slope of the Little Sioux valley along the abandoned wagon road leading east from Cherokee, in the southeast corner of section 26, Cher-

[9] Op. Cit., p. 415.

okee township (T. 92 N., R. 40 W.). It has been described by Carman[10] as follows:

"Nebraskan till is exposed in the lower part of the east slope of the Little Sioux valley along the wagon road leading east from Cherokee. The exposure extends along the road for more than 100 feet and for most of this distance the cut is ten to twelve feet deep. It covers a vertical distance of thirty-five feet and rises to an elevation of 1,250 feet above sea level, or approximately eighty feet above the river. The lower part of the exposure shows blue-gray compact gummy clay that is slightly calcareous and contains a few limestone pebbles. It has the typical starchlike fracture of the Nebraskan and at a depth of six to nine inches below the face of the exposure the clay is very compact and hard. The upper part of the exposure, about fifteen feet, is not the typical Nebraskan till, although it is very similar. This part is more plastic, looks like a massive silt deposit and breaks up into small fragments similar to the starch fracture. This zone contains calcareous matter as powdery material along the joints, and in the form of concretions whose diameters range from the size of sand grains to two inches, but no limestone pebbles were found and the matrix is thought to be leached. However, it is difficult to determine whether the effervescence produced is by a small concretion, by a small grain of limestone, or by a calcareous matrix of clay. It is believed that this zone is the Nebraskan gumbotil, that it was thoroughly leached before the Kansan epoch and that the calcareous material is all in the form of concretions and has been carried down from the Kansan till above. The upper contact of the Nebraskan till was not exposed, but Kansan till is exposed twenty-five yards farther east and twenty-five feet higher and this continues to the top of the slope."

Since Carman described this road cut east of Cherokee the road has been abandoned and a new road, primary number 5, made to the south of the old road. In making a satisfactory road grade from the Sioux river flood-plain level to the upland some splendid cuts were made. These cuts were studied by Carman and Kay in the summer of 1927 and again by Kay in 1928. The section is as follows:

At the base of the slope there is a cut in the lower part of which is gray unoxidized and unleached Nebraskan till, and in the upper part of which there is considerable secondary calcium carbonate in nodules or concretions. Above the unoxidized and unleached Nebraskan till there is about 8 feet of leached Nebraskan till or gumbotil. Farther along the road the Nebraskan gum-

10 Op. Cit., p. 420.

botil and Nebraskan till are ploughed by Kansan till. In depressions on the eroded surfaces of the Kansan till are Loveland silts which are overlain by Iowan till and gravelly till which in turn are overlain by Peorian loess. A composite section along this road from the east edge of the Little Sioux flood-plain to the upland about one-half mile farther east shows the following materials: Nebraskan till, Nebraskan gumbotil, Kansan till, Loveland silts, Iowan till and gravels, and Peorian loess.

On primary road 18 east of the crossing of the Big Sioux, in section 16, Lyon township (T. 98 N., R. 48 W.), Lyon county, there was exposed in the summer of 1927 a most interesting series of cuts. One and one-half miles east of Big Sioux river on the south side of the road the section is as follows:

		Feet
3.	Till, Nebraskan, sandy, brown color, leached	5½
2.	Till, Nebraskan, oxidized, highly calcareous, many concretions	3
1.	Till, Nebraskan, dark gray, unleached and unoxidized, highly calcareous, has concretions, cuts readily, starchlike fracture; exposed	8

In a cut to the east on the north side of the road and at a higher elevation, is a section as follows:

		Feet
5.	On slumped slope, many feet of gravelly till.	
4.	Silts, dark gray with purplish tint, concretions, no pebbles, laminations not distinct	4
3.	Silts, pebbly, gray, with dark carbonaceous streaks, highly calcareous	1
2.	Till, Nebraskan, oxidized, unleached, dark brown, chocolate-colored stains along many joints, breaks into irregular fragments, many lime concretions in upper part	10½
1.	Till, Nebraskan, unoxidized and unleached, dark gray color, much jointed, breaks into irregular fragments, brown stains on the joint faces, cuts readily, pebbles not abundant	6

A study of this section in relation to the preceding section farther down the slope reveals a thickness of 25 feet of unoxidized and unleached and oxidized and unleached Nebraskan till underlying the silts. Farther east, and continuing up the slope, there is a section as follows:

		Feet
7.	Till, Kansan, oxidized, unleached, many concretions, many pebbles, jointed, breaks into irregular fragments, to top of cut, 6 feet, but extends up the grassed slope.	
6.	Silts, in lower part gray to yellow in color; upper part gray to dark gray, calcareous, has concretions	6
5.	Silts, a definite dark brown band; a fairly dense clay, concretions, with concentration of concretions at the contact with overlying silts; no pebbles, fairly dense and somewhat tough, laminations not evident, highly calcareous	4

4.	Silts, very loesslike; a distinct band, cuts like loess and feels like loess, has concretions	3
3.	Silts, like number 5 in every respect	4
2.	Silts, very loesslike, exceedingly fine, light buff color, many concretions, lines of stratification seen on the surface, no shells seen, no pebbles	10
1.	Silts, dark, carbonaceous	3

By combining the two sections above it is possible to determine the thickness of the silts above the Nebraskan till to be about 30 feet.

Still farther up the slope is another good cut on the north side. The section is as follows:

		FEET
2.	Till, Kansan, oxidized and unleached, yellowish to brownish in color, cuts readily into irregular fragments	27
1.	Silts, gray, calcareous.	

The base of the next cut up the slope is at the same elevation as the top of the 27 feet of Kansan till in the cut down the slope. Here the section is as follows:

		FEET
2.	Loess, buff-colored, lowest 1 foot is gray and has iron tubules, unleached except the upper 3 feet, which is dark brown and leached	14
1.	Till, Kansan, oxidized and unleached, sand pockets	11

The top of this section is approximately at the upland of the region.

The total thickness of Kansan till revealed in these sections is 38 feet. A composite section of about 110 feet in thickness representing the kinds of materials to be seen in these splendid cuts is as follows:

		FEET
5.	Loess, buff-colored, lowest one foot gray and has iron tubules; unleached except upper 3 feet, which is dark brown and leached	14
4.	Till, Kansan, oxidized, unleached, has concretions, sand pockets, breaks into irregular shaped fragments, jointed	38
3.	Silts, alternating bands of dark brown chocolate-colored calcareous silts and lighter colored loesslike silts with no pebbles and highly calcareous and having concretions	30
2.	Till, Nebraskan, oxidized and unleached, dark brown, chocolate-colored stains along many joints, many lines of concretions, breaks into irregular fragments	10½
1.	Till, Nebraskan, unoxidized and unleached, dark gray in color, highly calcareous, has concretions, starchlike fracture	15

The silts in this section are interpreted to be of interglacial origin and to be Aftonian in age.

From a study of these sections and scores of other sections of

Nebraskan gumbotil, Nebraskan till and related materials, it has been found that a normal section may be represented by a diagram as in figure 34. It will be shown later that similar zones are characteristic of the Kansan drift.

Descriptions of the Nebraskan Drift Phases

The Nebraskan drift has several phases, each of which has characteristics which are fairly constant wherever the phase is

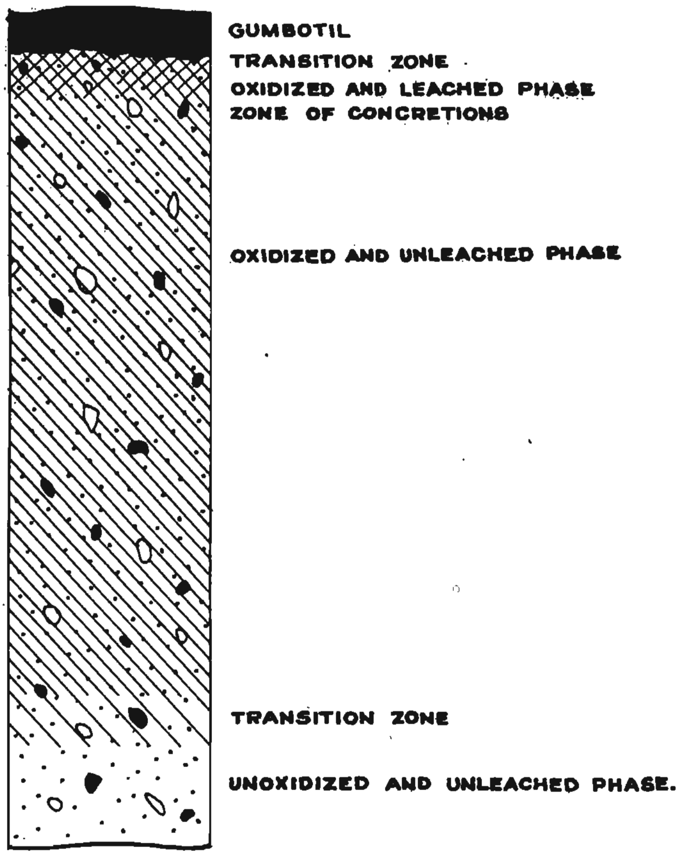

FIG. 34.—Diagram of a complete normal section of Nebraskan drift.

found. These phases include gumbotil, oxidized and leached drift, oxidized and unleached drift, and unoxidized and unleached drift. Each phase grades above and below into adjacent phases. Each phase will be described from studies made in the field and in the sedimentation laboratory.

THE NEBRASKAN GUMBOTIL

The Nebraskan gumbotil is the most weathered phase of the oldest Pleistocene till. It is very different from the till below it and from any till which lies on it. The color of the gumbotil is one of its most uniform characteristics. A dry surface is gray with a tendency toward shades lighter than neutral gray rather than the darker shades. Some slightly purplish or reddish tints are seen and where the gumbotil has been used for road bed material and has been pulverized by traffic it has a distinct ashen gray color. The wet gumbotil has a somewhat greater range in color than the dry gumbotil. When thoroughly wet it is dark gray with minor shades of purple and blue. A bluish tinge is common over the surface and streaks of dark rusty colors, due to infiltration of iron oxide, are seen on many of the broken surfaces. The colors of the gumbotil are in strong contrast to the yellows and browns of other phases of the till.

Another feature of the Nebraskan gumbotil as well as of gumbotils on the Kansan and Illinoian tills is that it is very sticky and plastic when wet, as it retains much capillary water. When water is removed by evaporation the upper part of the gumbotil shrinks in volume. The result is the development of a series of intersecting irregular angular cracks over the surface, which widen as the clay dries; the upper part of the gumbotil is separated into polyhedral blocks. These blocks range from about one inch to more than two inches in diameter, with the cracks from one-quarter of an inch to more than half an inch deep. Prolonged drying of the gumbotil produces secondary divisions of the surface into smaller areas which give the appearance of a crumbling loose layer of isolated fragments, as shown in figure 35. But this appearance is deceiving for the small blocks are rather solidly attached to the main mass of gumbotil although a zone of weakness at the base of the blocks serves to permit the breaking away of the blocks more easily than a lump of solid dried gumbotil can be broken. The small fragments when broken from the main mass are polyhedral, hackly faced, irregularly shaped forms. The larger blocks are separated by deeper cracks than are the smaller, but they do not appear to have developed the zone of weakness at the base of the block as have the smaller blocks. The angular cracks which separate the surface blocks

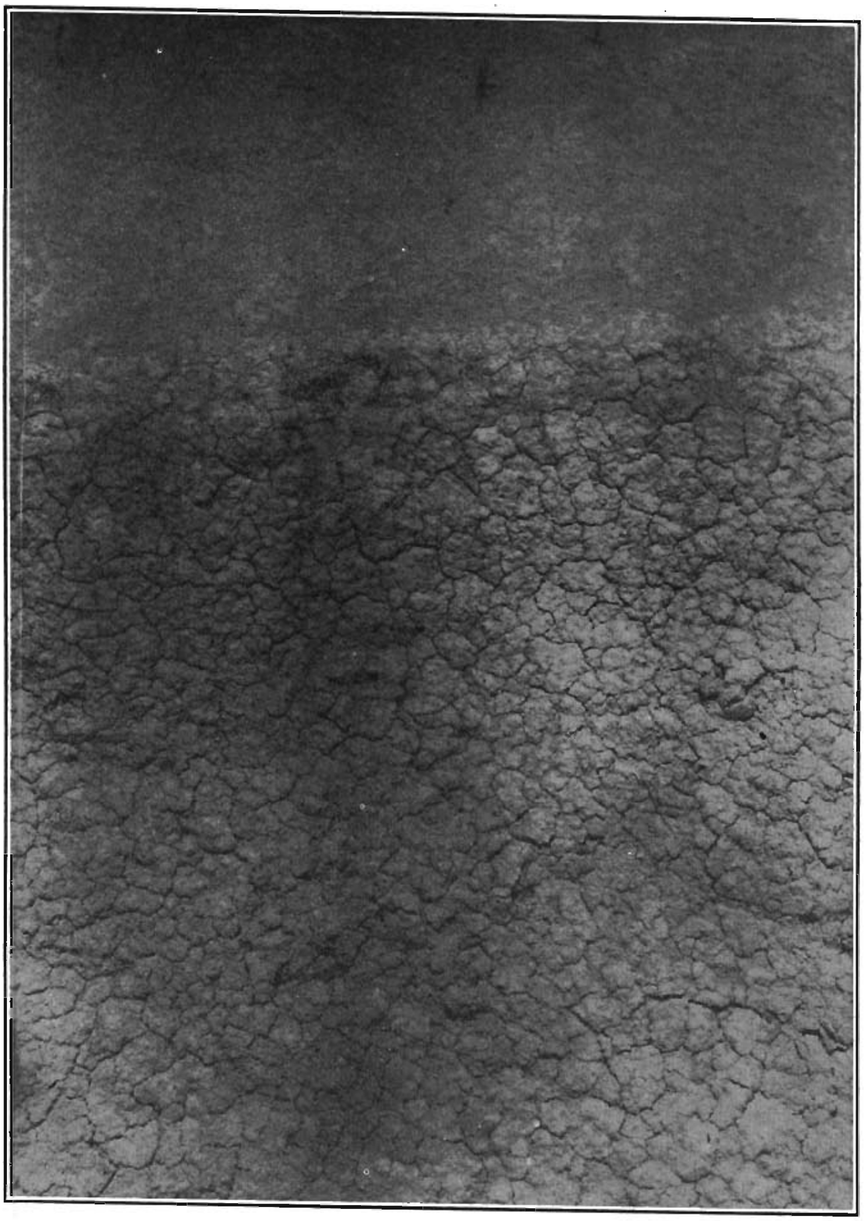

FIG. 35.—Showing dried surface of gumbotil with smooth loess surface above it. Both materials have had the same amount of exposure.

on the gumbotil have some of the features of mud cracks as developed in horizontally stratified muds. The chief difference seems to be in the irregularity of the cracks and in the control of the direction of the cracks by the surface features of the material. In the gumbotil there are sand and pebbles and iron cemented zones, hence, the cracks which cross its dried surface after it has been wet are not straight, nor do they seem to be directed by minor surface features as are typical mud cracks. The gumbotil cracks are sharply angular and the surfaces of the sides of the cracks are rough and may usually be matched. The cracking takes place on any gumbotil surface whether it be in a vertical, a sloping or a horizontal position.

Gumbotil is without stratification. At no place where it was studied does the material seem to have the even banding of color, separation of size grades, parting along flat surfaces, or differential surface weathering which would indicate deposition in layers. There are, however, exposures which show a stratified silt or a loess on the gumbotil. But neither the silt nor the loess is related to the gumbotil in origin.

The mass texture and the clastic texture of the gumbotil are characteristic features. By *texture* is meant the character and disposition of the constituent parts (particles) of a composite mass. Mass texture is used in this paper to mean the character and disposition of the joint or surface bounded units of till material, each of which is composed of sand in a clayey matrix. Clastic texture is used here to mean the character and disposition of the unit rock or mineral fragments constituting the deposit which these fragments are aggregated to form. Within the till there are units, composite in themselves, which are bounded by joints or surfaces along which separation takes place more easily than through the units. In some places these surfaces result in 'starchlike fracture', and in other places they result in faces of hackly appearance or with other characteristics produced by the presence of these separation surfaces.

The mass texture of the gumbotil is characteristic. Within the gumbotil are many surfaces along which separation takes place rather readily when the material is moist. The extreme division of the gumbotil along these surfaces results in small, irregular, polyhedral fragments. Surfaces which include many of the small fragments have a "hackly" appearance. The sizes of the small pieces range from about one-sixteenth of an inch to more than one-fourth of an inch. The forms are many-sided;

some of them approach the form of a sphere, others do not. In some specimens the corners or edges are projected into thin sheetlike plates which lie between two adjacent blocks; in other specimens the forms are flakelike with one dimension much less than the others; some have square margins and some taper off to thin edges. The faces of the polyhedral figures are usually slightly convex with the ridges of varying sizes and sharpnesses.

When the gumbotil is dry it does not separate readily along the surfaces which are the limits of the small pieces referred to above, but yields somewhat readily along wider spaced prominent joints which may be remnants of structure in the original till. The joints which are nearly vertical are apparently best developed. While these planes are prominent in the dry gumbotil they are usually not more noticeable than those along the smaller blocks in gumbotil which is moist enough to be moulded. It is suggested that probably the smaller surfaces and perhaps the more extensive series of joints are the result of movement within the gumbotil during the minor disturbances which must have occurred in the mass during its weathering and during the settling to its present compact condition.

The clastic texture of the gumbotil is somewhat variable. The gumbotil is made up of fine clay, sand grains, a few pebbles, and in some places fragments of sufficient size to be called cobbles and boulders. The amount of coarse detritus in the gumbotil differs greatly; in some places it gives to the material a distinctly sandy texture and it may even include numerous pebbles. Indeed the sand content may be so high that the clay present is barely sufficient to fill the spaces between the sand grains. In most specimens, however, the clay forms the major part of the gumbotil and is the constituent which determines its physical character.

The clay content of the Nebraskan gumbotil has a wide range. This is evident from field studies, but more particularly from laboratory studies. In the laboratory the size-grade distribution of the particles in the gumbotil above 1/64 millimeter in diameter was determined. The clay and silt below 1/64 millimeter were combined in the analyses and gave a range from 48 per cent to 79.3 per cent in the nineteen analyses which were made. The range between these figures is shown in the following table:

Percentage of clay and silt below 1/64 millimeter in diameter:	45-50	50-55	55-60	60-65	65-70	70-75	75-80
Number of analyses:	1	0	3	4	5	4	2

It will thus be seen that about two-thirds of the analyses show a content of silt and clay between 60 and 75 per cent with more analyses below the lower figure than above the higher figure.

The sand content shows prevailingly a greater percentage of the sizes between 1/16 millimeter and 1/32 millimeter than of any other grade, although the next smaller size, 1/32 millimeter to 1/64 millimeter, may be very close to the same percentage; in three analyses the grade 1/32 millimeter to 1/64 millimeter in diameter exceeded in percentage that between 1/16 and 1/32 millimeter. The percentages of the 1/32 millimeter to 1/64 millimeter grade range from 5.3 to 12.4 of the whole sample. The percentages of the 1/16 millimeter to 1/32 millimeter grade range between 7.3 and 23.5. The sand and pebbles which are coarser than 1/16 millimeter in diameter make from less than 1 per cent to more than 20 per cent of the sample. The maximum size of fragments found in the specimens analyzed was less than 16 millimeters.

The most conspicuous of the similar features is an approximation to the same percentages of the three grades, ½ millimeter to ¼ millimeter, ¼ millimeter to ⅛ millimeter, and ⅛ millimeter to 1/16 millimeter. The following table shows the striking number of times the figures approach each other, although here as in percentages of other characters there is no value common to all of them. Percentages of the whole specimen are given:

Spec. No.	64A	78A	202A	223A	236A	237A	239A	245A	269A	273A
1/2 to 1/4 mm.	1.6	3.1	3.1	7.2	2.6	1.7	0.1	1.6	2.5	2.6
1/4 to 1/8 mm.	2.7	3.4	3.9	5.8	2.3	2.0	0.2	1.6	2.4	2.6
1/8 to 1/16 mm.	3.6	3.7	5.1	4.9	2.2	2.2	tr.*	1.4	2.8	3.4

Spec. No.	276A	280A	291A	292A	295A	296A	302A	306A	307A
1/2 to 1/4 mm.	3.0	3.1	9.3	2.8	2.5	5.4	3.4	5.1	3.0
1/4 to 1/8 mm.	2.4	2.9	5.9	2.5	2.4	4.8	3.2	5.6	3.3
1/8 to 1/16 mm.	2.6	2.4	1.7	2.8	2.6	4.2	3.1	6.9	4.5

The Nebraskan gumbotil has physical features dependent upon the amount of clay in it. Mechanical analyses of the size grades as well as field observations show in different localities different proportions of clay and sand in the gumbotils. This is due to the differences in the original materials from which the gum-

* Less than 0.1 per cent.

botils were derived. In some places sands and gravels were at the top of the drift. During the time of gumbotil formation, the alteration in these sands and gravels produced a thoroughly leached and partly decomposed mass of coarse detritus.

Nebraskan gumbotil shows a predominance of those rocks and minerals which resist chemical weathering. As would be expected in a much weathered product, the limestones, dolomites, and other soluble rocks have been entirely removed by leaching. The average pebble content of several analyses of Nebraskan gumbotils made in widely separated areas is as follows:

	Percentage
Quartz	36.75
Chert, flint, etc.	21.25
Quartzite	20.25
Granite	8.25
Basalt and greenstone	11.00
Feldspar	1.25
Felsite	0.50

The content of siliceous pebbles is here more than 78 per cent. None of the Nebraskan gumbotil examined showed less than 72 per cent, and the highest showed 88 per cent of siliceous pebbles. The studies of leached and oxidized Nebraskan till showed about 38 per cent of siliceous pebbles, and the unleached and oxidized Nebraskan till showed about 15 per cent of such material.

In the sands washed from the gumbotil and separated into size grades there are some minerals with characteristics which indicate that their form is immediately derived from the disintegration of igneous rocks. There are numerous feldspar fragments, unrounded and showing under the microscope that they have undergone partial kaolinization. There are also hexagonal flakes of dark mica which show a coating of iron oxide, as would be true if they had been derived from rock fragments. There are quartz grains which show the imprint of crystals which were adjacent in the original rock mass. There are also quartz grains which are irregular in shape and which still have attached to them bits of mica or feldspar from the rock of which they were a part.

When pebbles from the Nebraskan gumbotil and underlying phases of the till are studied to ascertain the relative sizes of pebbles in the different horizons and to determine the shapes of the pebbles some interesting information is obtained. For example, one hundred pebbles collected from the Nebraskan gumbotil at one locality had dimensions as follows: largest pebble 24 by 14 by 10 millimeters; smallest 2 millimeters; and average pebble 8 by 5 millimeters. The shapes of these pebbles were subangular to spheroidal. The unleached and oxidized Nebraskan drift beneath the Nebraskan gumbotil had pebbles with dimensions as follows: largest pebble 62 by 45 by 17 millimeters; smallest pebble 3.4 millimeters; and average pebbles 17 by 15 by 10 millimeters. The pebbles were chiefly flat and subangular; some were appreciably rounded. The largest pebble in the Nebraskan gumbotil from another locality was 10 by 7 by 5 millimeters; the smallest 1.5 by 2 millimeters; and the average 3 millimeters; the shapes were subangular to spheroidal. Here the underlying Nebraskan till had pebbles the largest of which was 55 by 35 by 30 millimeters; the smallest pebble 3 by 2 millimeters; and the average 15 by 10 by 7 millimeters. The shapes of the pebbles were subangular to angular.

Some detailed laboratory work was done with reference to the roundness of the larger fragments of rock in the gumbotil. The roundness was determined by the simple expedient of rolling the pebbles down a mathematically designed curved inclined chute and then reading by means of a chart a roundness value for the distance rolled. The value .00 is the unit angularity or the figure for a fragment the shape of a cube. The value 1.00 is reserved for the perfect sphere, which a natural fragment probably never attains. The values between these two extremes then represent the proportional amount of rounding which particular pieces have undergone. The percentages given below are based on several hundred determinations for each size given.

Pebbles from the Nebraskan gumbotil of the size from 8 millimeters to 16 millimeters in diameter gave the following roundness values:

Roundness:											
.00	.03	.06	.10	.15	.19	.24	.26	.29	.33	.36	.40
Percentages:											
34	21	18	14	10	1	1		1			

The values for the pebbles between 4 and 8 millimeters in diameter were determined to be as follows:

Roundness:	.00	.01	.07	.13	.17	.23	.27	.31	.36	.40	.44	.48
Percentages:	22	19	18	15	13	7	2	2		1		1

Those pebbles between the sizes of 2 and 4 millimeters gave the following roundness figures:

Roundness:	.00	.06	.14	.20	.26	.32	.37	.44	.48	.53	.59	.63
Percentages:	21	14	21	18	9	9	3	3	1	1		*

The distribution of the percentages shows a fairly regular gradation from the angular pebbles down to those showing maximum rounding. In the 16 to 8 millimeters size, the largest size for which determinations were made, the fragments have a rather well defined upper limit for the rounding. This is between the values of .15 and .19, for only 3 per cent of the total lies above the latter figure, while 10 per cent shows a value of roundness .15. The other sizes show a more gradual decrease in percentage, though a rather marked drop in percentage is noted near roundness .20 in each case. The upper limit is not very definite for any of the sizes. In the smaller sizes a few well rounded quartz pebbles gave the higher roundness figures, and in the largest size a number of cherts and a few quartz pebbles gave the higher figures for these grades. There were obtained figures of roundness .40 and .63 for the largest and smallest sizes respectively, but in each case the determinations were less than half of one per cent of the whole, so they were not separated in the averages.

The pebbles which show the moderate rounding include in most cases those which are composed of igneous rocks. The alteration of the pebbles, which took place during the formation of the gumbotil, began along the edges and corners of the fragments, tending to round them. The break found in the percentages of roundness values probably shows about the upper limit of rounding by the disintegration of the fragments in the gumbotil. Many of the chert and quartzite pebbles and some of the quartz pebbles have one or more broken faces which have had the edges but little rounded since the fracture. It is this kind of fragment which predominates in the angular and less rounded

* Highest roundness value obtained for the size, but less than one-half of one per cent in the average.

percentages and on which is superimposed the percentage of roundness values of the other rock fragments. There were not available sufficient pieces of rocks other than the siliceous types to make separate determinations to be compared with the roundness values of the siliceous fragments.

The Nebraskan gumbotil has distinctive features as a glacial drift material. Foremost is its gumbo character. Water applied to the surface forms a clay slip which is very slippery. Soaking with water causes it to become very plastic and tough, although the dry material is hard and tenacious. The color and surface weathering of gumbotil are striking features. The gray to drab color, lighter on the washed surface because of the exposed sand, and the polyhedral fracture of the surface are characters which taken together make it conspicuous in drift exposures and help to distinguish it from the other phases of the drift.

THE OXIDIZED AND LEACHED NEBRASKAN TILL

The oxidized and leached Nebraskan till lies immediately below the gumbotil. The oxidized and leached phase in most places is not separated sharply from the phase above, but transition from one kind of material to the other is through a narrow zone in which there is distinct interfingering of the two phases.

The prominent difference between the gumbotil and the oxidized and leached till is one of color. The color of the oxidized and leached till is in most places brown or brownish yellow. Along the joints the color is usually somewhat different from the color of the mass. This color in the upper part of the zone is the color of the gumbotil where the alteration has penetrated below the general level of gumboization. Some of the joint surfaces in the mass of leached material are coated with thin layers of iron oxide which is darker in color than the till, marking smoothed surfaces into patches with dark boundaries.

The wet oxidized and leached till does not have the very sticky and plastic character which is possessed by the gumbotil. In places it will form a clay slip, but in places there is insufficient of the very fine material to permit its formation.

The exposed surface of the oxidized and leached till is not of the same character as the surface of the gumbotil although there are similarities. The cracks which form in the surface after wetting are not as large as those which mark the gumbotil surface and the tops of the blocks are crossed by fewer smaller cracks, which gives to the surface a less crumbly appearance than that of the more altered gumbotil.

The mass texture of the oxidized, leached Nebraskan till and the clastic texture differ from these features in the gumbotil. The fingerlike extensions of the gumbotil into the zone below follow joints which are continuations of the larger joints in the gumbotil. These extend through the oxidized and leached zone and within this zone they are increased in number by a series of smaller, closely spaced joints which permit the material to be separated into angular blocks. These blocks are of different sizes but are generally larger than the small blocks which are found in the gumbotil. The same type of fracture appears to develop whether the material be wet or dry, whereas in the gumbotil only the moist mass shows distinctly the smallest joints. There is a tendency for the oxidized and leached till to show wider spacing of the joints, both large and small, toward the bottom of the zone, while at the top the gradation of the joint system into gumbotil is gradual, and is not sharply set off by any abrupt change in the nature of the fracture.

The clastic texture of the oxidized and leached phase is somewhat coarser than is that of the gumbotil. The clay matrix is not as fine as in the gumbotil and it includes more sand. Pebbles are more numerous in the outcrops than in the zone above.

In the laboratory, mechanical analyses of the oxidized and leached Nebraskan till show major features similar to the major features of the gumbotil. The percentage of the 1/16 millimeter to 1/32 millimeter grade is higher than the percentage of the next smaller grade, perhaps somewhat more persistently higher than in the gumbotil. The three sand grades, ½ to ¼ millimeter, ¼ to ⅛ millimeter, and ⅛ to 1/16 millimeter, show the same parallelism in percentages although the percentages in the oxidized and leached till are nearly twice the average percentage in the gumbotil, being in most cases about six per cent for each of the three grades. The silt and clay content is the greatest of any of the grades, but it is not as high as in the gumbotil. Most of the analyses show between fifty and fifty-five per cent of the material to be less than 1/64 millimeter in diameter, whereas in the gumbotil three-fourths of the specimens showed over sixty per cent of the same size grades. In the specimens analyzed the samples were too small, about fifty grams, to include large pebbles, although some of 4 to 8 millimeters and even 8 to 16 millimeters in size occurred in the random samples used. Fragments over 1/16 millimeter diameter in the gumbotil form from one to twenty per cent of the whole sample; in the oxidized and leached Nebraskan till the percentage of material over 1/16 millimeter grade ranged in the specimens studied between 24 and 30 per cent.

It is seen from these comparisons that the Nebraskan gumbotil is somewhat finer in texture than the oxidized and leached Nebraskan till. The two have in general the same textural qualities which are dependent upon the clastic content with the exception that the oxidized and leached till does not have the very fine clay which gives to the gumbotil its distinctive physical characteristics. The development of the finer clay and the reduction of the textural range would result from long continued chemical weathering of such material as oxidized and leached till.

The siliceous content of the oxidized and leached Nebraskan till is shown from pebble analyses to be lower than is that of the gumbotil. The average of three typical analyses gave the following:

	Per Cent
Chert	15
Quartz	14
Quartzite	13
Schist	2
Felsite	3
Granite	19
Basalt and greenstone	29
Dolerite	1
Unidentified	4

The percentage of siliceous pebbles is only 42; in gumbotil it is rarely less than 75. The granites, basalts, and greenstones are more abundant than in the gumbotil and most of these pebbles show considerable surface alteration. There are many rotten pebbles which go to pieces very readily; some may be crumbled between the fingers. Several kinds of igneous rocks are represented by the pebbles, the most common being those containing abundant ferromagnesian minerals.

The oxidized and leached Nebraskan till has distinctive characteristics by which it may be readily distinguished from the gumbotil. Prominent among these are the color differences, the aspect of the weathered surface, and the plasticity when wet. The jointing of the mass, the lithologic content, and the texture are similar but sufficiently different so that any one of these may be used as an indicative criterion for the determination of the phase of till represented. No sharp line can be drawn between the zone of oxidized and leached till and that of the gumbotil, as there is a transition zone through which one merges into the other.

The thickness of the oxidized and leached till beneath the Nebraskan gumbotil differs from section to section, but the most prevalent thickness is about two feet. In the Kansan and Illinoian tills the corresponding zones are thicker.

THE OXIDIZED AND UNLEACHED NEBRASKAN TILL

Below the oxidized and leached till is oxidized and unleached till. In the Nebraskan drift this phase is in places more than forty feet thick, as measured in cuts made in steep slopes. It grades above into the oxidized and leached phase and below into the unoxidized and unleached Nebraskan till. The contact between the oxidized and unleached phase and the oxidized and leached Nebraskan till above is in many places sharp, the two phases being recognizable within an inch of each other. However, in most places leaching has extended down along joint surfaces into the oxidized and unleached till, the result being that the surfaces of joint-bounded blocks are leached while the interiors of the blocks are still highly calcareous.

In many sections of Nebraskan drift the oxidized and unleached zone is not well exposed. It is a typical boulder clay but may include some sands and gravels. The color is yellowish to brownish and is distinctly lighter than that of the oxidized and leached zone. The wet surface is appreciably darker than the dry surface.

The surface weathering of the oxidized and unleached till results in the formation of numerous cracks which separate the till into blocks. The cracks are not as large nor are they as numerous as in the Nebraskan gumbotil and in the oxidized, leached Nebraskan till. Smaller cracks are associated in places with the larger cracks which divide the surface into angular patches several inches across. The large cracks are the first to develop, and on a surface only partly dry they are the only cracks present. With continued drying there are developed smaller fissures separating surface blocks an inch or two across which give a checkered appearance to this dried till.

The smaller surface blocks are about the size of the larger ones on the surfaces of the gumbotil and of the oxidized and leached till. The larger blocks of the oxidized and unleached phase are not distinctly represented in the phases above. The differences in surface character are due no doubt to the differences in clay content. The greater proportion and fineness of the clay in the gumbotil and in the oxidized and leached phase enables these tills to retain more water when wet and hence to shrink more when dried, thus developing more cracks than does the oxidized and unleached till.

The body texture of the oxidized and unleached Nebraskan till is the result of a series of vertical and horizontal joints which are spaced from one-half inch to three inches apart. The till breaks readily along the joint planes into angular blocks, usually with rectangular outlines. The sizes of these blocks differ with the spacing of the joints; the usual sizes are from less than one inch to several inches in the different dimensions, and while there is no sharp upper or lower limit of size there is a very distinct range into which most of the pieces fall.

The joints in the till are the planes along which the water penetrates the most readily, and hence are the planes along which weathering first takes place. This is particularly noticeable in the contact zone with the oxidized and leached till where, finger-like, the leached till follows the joint planes for several inches below the upper limit at which the till effervesces with acid. Below the leached phase the waters which were charged with lime from the upper phases entered a different environment, where they precipitated some or most of the lime they carried. In some places this secondary calcium carbonate accumulated about distinct centers and became concretionary masses with more or less regular surfaces. In most places, however, lime was deposited along the joint surfaces which the solutions followed, filling them with white calcareous material which is easily reduced to powder when dry. The secondary calcium carbonate is a distinctive feature of the upper part of the oxidized and unleached phase, and even when the gumbotil and the oxidized and leached phases have been removed by erosion the secondary carbonate along the joints is evidence of the former existence of overlying phases which once contained calcium carbonate.

The clastic content in exposures of the oxidized and unleached till is somewhat striking; a yellowish colored clay matrix encloses sands, pebbles, and larger fragments. The joints which separate the till into the characteristic blocks have formed without apparent regard to the larger fragmental content of the clay; they have surfaces in which are partly embedded sand grains and pebbles with the mould of the protruding part in the opposed surface. The pebbles and finer particles are distributed promiscuously through the clay, which in normal till has no lines of stratification.

The upper limit of size of rock in the Nebraskan till is that of the large boulders which occur in places. The larger are several feet in diameter and are of the same kinds of rock as the cobbles and pebbles. Boulders are not abundant in the Nebraskan drift; in most exposures the upper limit is within the size of cobbles.

In the laboratory, mechanical analyses of the oxidized and unleached till reveal about the same characters as the oxidized and leached till shows. Most of the ratios of percentages are about the same in both types. There is, however, a noticeable increase of the coarser material and corresponding decrease of the clay and silt grades. In some analyses there is less than 45 per cent of grade sizes below 1/64 millimeter, showing clearly that in the oxidized and unleached till there is less clay and silt than in the oxidized and leached till and in the gumbotil. There is in general a decrease in percentages of the sizes from 1/2 millimeter up to the coarsest of material present.

The oxidized and unleached till, except in degree of color and weathering of materials, is much like the oxidized and leached till above and in some respects it is similar to the gumbotil. A comparative study of the gumbotil, the oxidized and leached till, and the oxidized and unleached till shows that the oxidized and unleached till contains the coarsest materials. The same general ratios of size grades seem to indicate a genetic relationship between all three kinds of till. Theoretically, weathering should reduce the sizes of fragments in a till and the studies in the field and in the laboratory show that the most weathered material, the gumbotil, has the fragments most reduced, and the oxidized and unleached till the least reduced of these three phases; the oxidized and leached till is intermediate.

The pebble analyses of the oxidized and unleached Nebraskan drift show pebbles of kinds of rock which are rare or absent in the more weathered zones. Limestone, which is not found in the gumbotil or in the oxidized and leached phase, is in most places an important constituent of the oxidized and unleached till. An average of fourteen analyses shows 44.6 per cent of limestone and dolomite pebbles. Granites, greenstone, and basalt pebbles also are numerous. Chert and quartz, which are so abundant in the gumbotil and which are well represented in the oxidized and leached zone, make up together only 7.6 per cent of all the pebbles. The average of the fourteen pebble analyses is as follows:

	Per Cent
Limestone and dolomite	44.6
Shale	1.0
Sandstone	1.9
Quartz	3.3
Chert	4.3
Quartzite	5.7
Schist	.2
Granite	13.3
Basalt and greenstone	25.1
Unidentified	.6

Some of the rocks are much weathered and some of the limestone has a coating of leached clay. But, as a whole, the rocks which are in the oxidized and unleached Nebraskan till show less weathering than do those in the overlying related till. In some parts of the oxidized and unleached phase there has been apparently almost no modification of the rocks since they were deposited by the ice, for the edges of some of the fragments are sharp, striæ are found on limestone surfaces, indicating freedom from solution, and the colors of the minerals on freshly broken surfaces show very little change due to weathering. The weathering of the rocks represented by the pebbles of the unleached till would result in materials with the characteristics now shown by the oxidized and leached till and the gumbotil.

The roundness of the pebbles in the oxidized and unleached Nebraskan till has a somewhat different distribution from the roundness of the gumbotil pebbles. About 40 per cent or slightly more of the pebbles between 4 and 16 millimeters diameter in the oxidized and unleached till show angularity. The first percentages of distinctly rounded groups are 11 and 12 per cent with a roundness value of .07 and .03 respectively. The next groups show percentages of 18 and 16, from which the percentages diminish to the limit value of roundness of the pebbles. If the rounding of the pebbles by ice action and the fracturing of rounded pebbles to increase the number of angular pebbles be assumed to balance approximately, then the roundness of the pebbles in the oxidized and unleached till may be used to indicate the proportion of till derived by the ice from loose residual material and from the bedrock. If the angular pebbles represent those derived by ice action from bedrock, then about 40 to 45 per cent of the pebbles between 4 millimeters and 16 millimeters in diameter are so derived. Weathering would increase the rounded pebbles with a corresponding decrease in the number of angular pebbles, tending to make an even distribution throughout the roundness values.

The oxidized and unleached Nebraskan till grades upward into the oxidized and leached till phase and downward into the unoxidized till phase. It represents therefore a stage in the alteration of the drift. The oxidized and unleached till has several times the thickness of the combined gumbotil and oxidized and leached phases. Oxidation is therefore shown to be the most rapid change which takes place in the till. The three phases of the till which have been described constitute three distinct horizons, each differing somewhat in thickness and each distinct in characteristics, which are the product of weathering changes in the till. These changes take place in regular order to successively greater depths, first along joint surfaces and then toward the interior of joint-bounded blocks.

THE UNOXIDIZED AND UNLEACHED NEBRASKAN TILL

Beneath the oxidized and unleached till is unoxidized and unleached till. But only in a few places in the state have good sections of the unaltered Nebraskan till been found. In most places where observed in the state this till is dark gray when moist with a distinctly bluish cast on a freshly exposed surface. The dry surface has a brownish gray color, the brown tint being due to a thin film of oxidized material which forms very readily when the till is exposed to the air. The yellow color of the oxidized till is in many places developed along joint surfaces in the unoxidized, unleached till. In some places the blocks of till which are separated by joints are unoxidized only in the center of the blocks.

The color of the unoxidized and unleached Nebraskan till is its most distinctive feature. The mass and clastic textures are almost identical with those of the oxidized and unleached till. The lithology of the unoxidized and unleached till and the roundnesses of the pebbles are very similar to those features in the oxidized and unleached till and hence will not be separately described. As was stated in a previous part of this report, the unoxidized and unleached Nebraskan till of parts of northwestern Iowa has characters quite different from those of the unoxidized and unleached Nebraskan till in other parts of the state. This different character is due probably to the inclusion of much shale from rocks underlying the drift. The unleached till resembles the gumbotil more than the usual unweathered phase of the material.

The lowest phase of the Nebraskan drift is so deeply buried in most places that it is seldom exposed. This drift has been buried under the Kansan in all places in the state except in the extreme northeastern part. The erosion of this upper material and of most of the Nebraskan is necessary to uncover the unaltered oldest drift. Such erosion has taken place only in the southwestern part of Iowa and there only along the main drainage lines. Most of the valleys are cut only slightly below the level of the Nebraskan gumbotil and therefore expose only the upper phases, including a portion of the oxidized and unleached till. In many places where the bottom of the drift has been reached either by erosion or by excavation, the drift is so thin that at least oxidation has penetrated to its base.

Thickness of the Nebraskan Drift

The depth to which the surface of Iowa was covered by Nebraskan drift may be estimated by (a) the amount of bedrock relief which was smoothed over to form the Nebraskan ground moraine plain on which the Nebraskan gumbotil was developed; (b) the amount of Aftonian erosion in Nebraskan drift; and (c) the elevation of the Nebraskan gumbotil plain above the bedrock surface.

The relief of the bedrock surface is discussed in Chapter I, where it is stated that the local relief of the surface at the time of the Nebraskan ice invasion was as great as 300 to 400 feet, although there were areas where the bedrock relief was slight. The Nebraskan drift so covered this uneven surface that the new surface was a comparatively level ground moraine plain. This surface continued until after several feet of gumbotil had been developed from the till and this gumbotil is the present testimony of the existence of an extensive drift plain. A drift mantle which would cover the pre-Nebraskan bedrock surface to sufficient depth to make the surface a plain would of necessity be a massive drift.

The agents of erosion which dissected the Nebraskan gumbotil plain within Aftonian time persisted long enough to cut valleys in bedrock to depths of more than 400 feet in the vicinity of Mississippi river in the northeastern part of the state. But over much of the state Aftonian erosion occurred only or chiefly in Nebraskan drift as is indicated by the relatively few areas of sharp bedrock relief beneath the drift (see Chapter I) and the occurrence of Nebraskan drift in numerous localities. If the drift had been thin it probably would have been largely removed by erosion during the long Aftonian interval.

The depth to which the bedrock surface was buried by Nebraskan drift may be determined by the elevation of the Nebraskan gumbotil above the indurated rocks. The construction of a set of profiles across the state showing the average elevation of the bedrock, above which the known elevations of the Nebraskan gumbotil plain are plotted shows that there are differences in depth of rock covering by the gumbotil-topped Nebraskan drift. In the western part of the state, in the vicinity of the Height of Land, the Nebraskan gumbotil lies 100 to 300 feet above the average elevation of the bedrock as determined from available data. The greatest thickness is in the west-central part of the state, with thinner Nebraskan drift to the north and south. In southwestern Iowa the Nebraskan drift when deposited was probably 75 feet to 100 feet thick, thinning gradually to the east. The few Nebraskan gumbotil outcrops in the eastern, central, and northeastern parts of the state show the Nebraskan drift in those areas to have been more than 100 feet in average thickness, although just how much of the bedrock relief on which this figure is based was developed in Aftonian time is not definitely known. Such drift thicknesses, which are average figures, show that a considerable body of transported débris was deposited by the Nebraskan ice.

The position of the Nebraskan gumbotil plain indicates that probably the thickest Nebraskan drift was deposited in the west-central part of the state, with the northern and eastern extensions having only slightly lesser thicknesses. The thinner drift was deposited to the south and southeast of the thick drift region, but still with sufficient depth to smooth the surface to an extensive plain.

The relatively large areas in which there is now found Nebraskan drift which survived the long Aftonian erosion, together with the evidence of the kind of surface which the drift mantled, indicate that the average thickness of the drift was greater than it has generally been believed to be. It was probably more than 100 feet thick as an average for the state, and may perhaps have been as thick as 150 feet.

CHAPTER V

THE AFTONIAN INTERGLACIAL STAGE

The Aftonian interglacial stage is the oldest of the four interglacial stages recognized in the present classification of the Pleistocene deposits of Iowa. The name Aftonian was used first by Chamberlin[1] in 1895, in connection with interglacial deposits separating the two oldest tills in the Afton Junction-Thayer region, Union county, Iowa. As was stated on page 76 of this report, the name was applied to the horizon represented by soil bands, peat, and muck, and was correlated with the forest bed horizon of McGee in northeastern Iowa. Below the Aftonian in the Grand River pit of the Afton Junction region there is Nebraskan till with associated gravels. Overlying the till and gravels is Kansan till. These gravels separating the two oldest tills have been for many years known as Aftonian gravels, not because of the time of the deposition of these gravels, which was during the closing stages of the Nebraskan glacial epoch, but because the weathering of the gravels occurred during the Aftonian interglacial epoch.

The Aftonian Record

The Aftonian interglacial stage is represented in Iowa by widespread Nebraskan gumbotil, peat, mucks, old soils, weathered sands and gravels, and other evidences of a long interval

[1] Chamberlin, T. C., The Classification of American Glacial Deposits: Jour. of Geol., Vol. III, pp. 270-277; 1895.

between the retreat of the Nebraskan ice sheet and the coming of the Kansan ice sheet. The Aftonian deposits are exposed by erosion in many places in the state and have been made available for study also in railroad and road cuts and have been penetrated in many well drillings.

The evidence indicates that when the Nebraskan ice sheet withdrew from Iowa the bedrock relief had been largely effaced by the Nebraskan glacial and fluvioglacial materials and a ground moraine plain with but slight relief was the prevailing surface feature of the whole state. The chief basis for this judgment is the widespread distribution and topographic position of Nebraskan gumbotil. The history of Aftonian time is recorded in considerable part by the changes which the Nebraskan materials of the ground moraine plain underwent by weathering and by the modifications of the plain itself by erosion during the time between the Nebraskan glacial stage and the Kansan glacial stage.

In several places in the state Aftonian peats, soils and weathered sands and gravels of Aftonian age have been found. Sections will be given in this chapter to show the characteristics of these interglacial deposits.

The Aftonian record is the record of an interglacial stage of long duration. It is impossible to state with any degree of definiteness, however, the number of years involved in this stage, but the time is to be measured in hundreds of thousands of years rather than tens of thousands of years.

Sections Representing the Aftonian in Western Iowa

The Nebraskan drift has been shown to be separated, in many places in Iowa, from the overlying Kansan drift by Nebraskan gumbotil. This Nebraskan gumbotil has significance as an Aftonian horizon marker because it was developed over wide areas under distinct topographic conditions. The weathering of Nebraskan till to gumbotil took place within the Aftonian interglacial interval, and hence might quite properly be given detailed consideration here. However, the gumbotil is so intimately related to the Nebraskan till that it was described as a phase of that till. It will be discussed in this chapter only as a part of the evidence of the Aftonian interglacial stage.

GRAVELS OF THE AFTON JUNCTION-THAYER REGION

Until the importance of Nebraskan gumbotil as an Aftonian horizon marker separating the Nebraskan till from the Kansan till was recognized a few years ago other materials were emphasized as bases for separating the Nebraskan till from Kansan till. Chief among these criteria were weathered sands and gravels and peats lying between the two oldest tills. Type sections

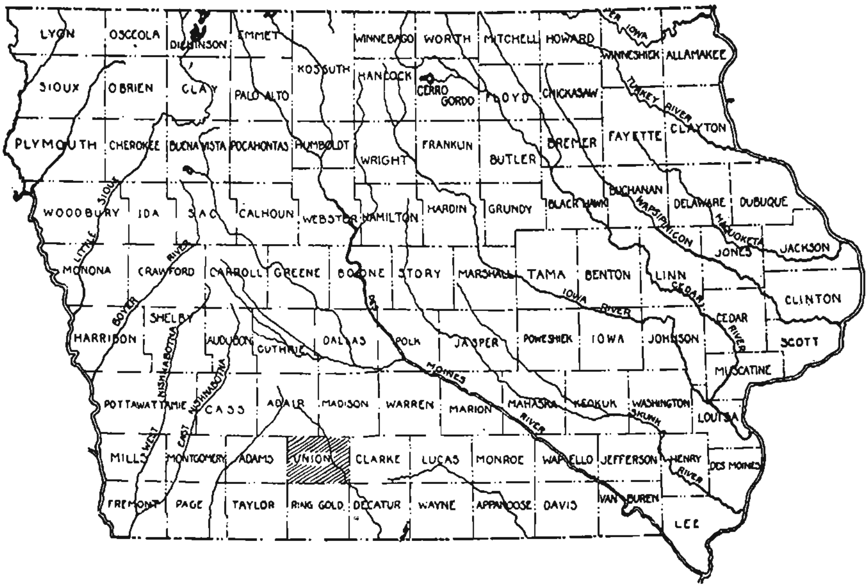

FIG. 36.—Map of Iowa showing the location of Union county.

of the two oldest tills separated by gravels are in the region of Afton Junction and Thayer in Union county in southwestern Iowa, the location of which is shown in figure 36. In fact, the Aftonian gravels in this part of the state are so well known by students of Pleistocene geology that one hesitates to state that a restudy of these famous exposures and other exposures in the same region has revealed evidence which seems to justify further discussion of the origin and relationships of these gravels, and to warrant question being raised with regard to some of the former interpretations.

From the time the gravel pits of this area were opened more than thirty-five years ago and their interesting characteristics revealed, they have been visited by many glacial geologists of America and of Europe. Some persons have come merely to see the type sections of the two oldest tills, now known as the Nebraskan till and the Kansan till, separated by the gravels which for many years have been called the Aftonian interglacial gravels; others have come to study carefully the characteristics of the

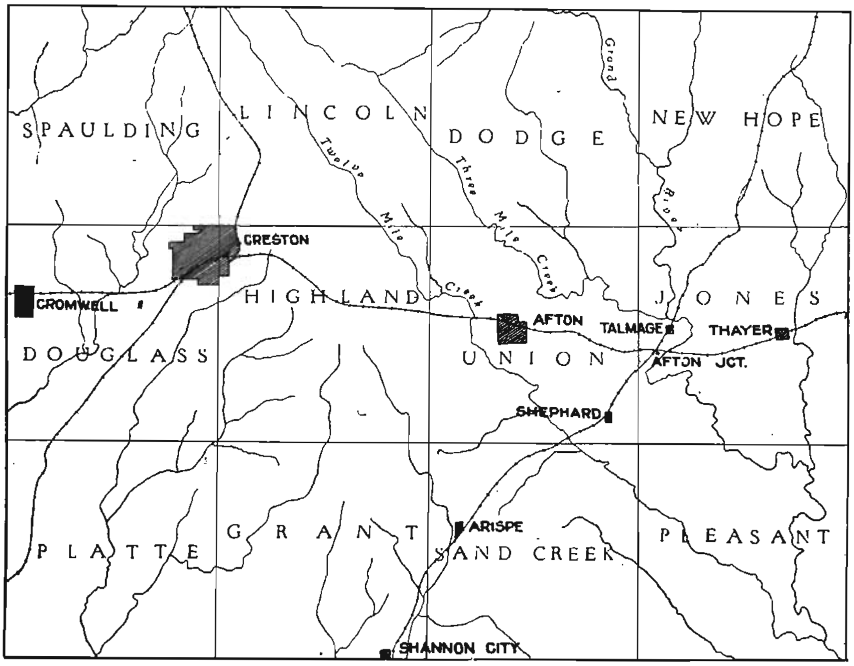

FIG. 37.—Map of Union county.

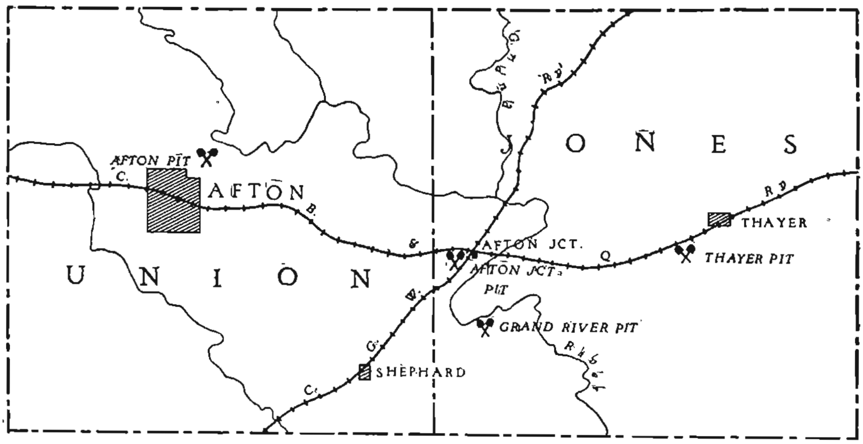

FIG. 38.—Map of Union and Jones townships, Union county, showing locations of the gravel pits discussed in this report.

tills and gravels and their inter-relationships. The most important contributions dealing with these gravels and associated deposits have been made by Dr. T. C. Chamberlin, Dr. H. F. Bain, and Dr. Samuel Calvin.[2]

The chief gravels are exposed in three gravel pits in Jones township and a gravel pit in Union township, Union county, figure 37. The locations of the pits are shown on the accompanying map, figure 38. One pit, known as the Afton Junction pit, is about 200 yards west and somewhat south of Afton Junction station on the Chicago Great Western railway, and of Great Western Crossing on the Chicago, Burlington and Quincy railway; a second pit, called the Grand River pit, is on the south bank of Grand river more than a mile southeast of Afton Junction station; the third pit in Jones township is the Thayer pit and is about three-fourths mile southwest of Thayer station. All of these pits have been abandoned for more than thirty years. Northeast of Afton, Union township, a pit was opened only recently and from it gravels are still being taken. This will be called the Afton pit.

When the now abandoned gravel pits were studied by Chamberlin and by Bain, the crossing of the Chicago Great Western railway with the Chicago, Burlington and Quincy railway was about one-half mile south of the present junction of these two railways. This fact must be kept in mind when the earlier geological reports of this region are being read.

The till below the gravels was named many years ago the Pre-Kansan or Sub-Aftonian till, but more recently it has been called the Nebraskan till. The till above the gravels has long been known as the Kansan till and the gravels separating the tills are the Aftonian gravels. In Chapter III of this report there is a discussion of these most interesting gravels, including the evidence upon which they were differently interpreted by different authors. Suffice it to say here that Chamberlin interpreted the gravels to be kamelike deposits on the surface of the Nebraskan drift and related in age to this drift. Bain referred to evidence of lateral transition from gravels into boulder clay and suggested the possible contemporaneity of the gravels with the Kansan till. Calvin in 1905 interpreted these gravels to

2 Specific reference to the works of the authors cited in this chapter will be found in Chapter III on the History of Investigations and Classifications, in this report.

be deposits made by torrential floods during the retreating stages of the pre-Kansan ice. Later, in 1908, as a result of studies by himself and Doctor Shimek of gravels and their included fossil faunas in western Iowa, Calvin suggested a modification of his former view regarding the origin of the Aftonian gravels in the Afton Junction-Thayer region. He expressed the judgment that the most satisfactory interpretation of the gravels is that they are strictly interglacial in age, having been deposited during the progress of the Aftonian interval, neither at its beginning nor at its end.

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

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

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

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

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

A section in the southwest corner of the old Afton Junction pit shows till and related materials. The section is about 200 yards south of a railroad cut in the base of which many years ago Aftonian gravels were exposed and were described by Calvin.[3] With reference to the Aftonian gravels in this railroad cut it is worthy of note that Frank Leverett reports that more than twenty-five years ago he and Douglas Johnson found near the west end of the cut some carbonaceous material overlying the gravels and underlying thirty feet or more of Kansan till. The elevation of the surface of these gravels, it is well to emphasize here, is less than ten feet lower than the top of the section in the Afton Junction pit. The elevation at the top of the section to be described is about 1120 feet above sea level. The section in the southwest corner of the Afton Junction pit is as follows:

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

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

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

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

A pebble analysis of the unleached till in 2 of the section is as follows:

	Per Cent
Limestone	49
Granite	16
Basalt or greenstone	21
Quartzite	5

[3] Calvin, S., The Aftonian gravels and their relation to the drift sheets in the region about Afton Junction and Thayer. Proc. Davenport Acad. Sci., Vol. X, pp. 18-31, 1907.

Quartz	2
Chert	5
Undetermined	2

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

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

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

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

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

The third section which is to be described and which shows the relations of Aftonian gravels to Nebraskan till is in the Afton gravel pit in the northeast quarter of section 16, Union township (T. 72 N., R. 29 W.), Union county, northeast of Afton. This pit was opened recently to secure road making material and is still being used. The pit is at the end of a spur which extends into the flood-plain of Three Mile creek. This spur has a gentle slope and the gravels are close to the surface. Above the gravels is about three feet of oxidized and leached till. The gravels in the deepest part of the pit are between 20 and 25 feet thick. They are highly oxidized, their color being dark yellow to chocolate; they show lens and pocket structure; and they are highly calcareous. The gravels are interbedded with some sandy and silty layers; in places the gravels and sands are cemented, and conglomeratic till balls are present. Cobbles above two inches in diameter are rare, though a few boulders about two feet in greatest diameter were seen. The elevation at the top of the gravels is about 1130 feet above sea level. About one mile north of the gravel pit in the northwest quarter of section 10, Union township (T. 72 N., R. 29 W.), is an exposure of Nebraskan gumbotil underlain by Nebraskan till and overlain by Kansan till. The elevation of this Nebraskan gumbotil is about 1170 feet above sea level. A similar Nebraskan gumbotil outcrops about one mile south of Afton, also at an elevation of about 1170 feet. This evidence indicates that before erosion of the Nebraskan gumbotil plain began in this area in which the gravel pit is included the elevation of the gumbotil plain was about 1170 feet above sea level. This is 40 feet higher than the elevation of the gravels and on this evidence the gravels are interpreted to be part of the Nebraskan drift. They are not in any sense Aftonian gravels as previous to this time they have been interpreted to be.

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

OTHER GRAVELS IN WESTERN IOWA

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

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

2. In western Iowa it has not been possible to distinguish the Nebraskan till from the Kansan till by differences in color, texture, lithologic composition, or degree of weathering. Only when it is possible to establish the relationship of an outcrop of till and associated gravel to gumbotil or other interglacial material whose age is known can the definite age of the till and gravels be determined. When the till is overlain by Nebraskan gumbotil or can be shown to lie lower topographically than nearby rem-

nants of the eroded Nebraskan gumbotil plain, then the till generally may be interpreted as being Nebraskan till. If, however, an outcrop of till is overlain by Kansan gumbotil, or if the till has the proper relation topographically to remnants of the eroded Kansan gumbotil plain, the till may be interpreted as being Kansan till.

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

4. Many mammalian fossils have been found in the sands and gravels associated with the tills of western Iowa. Calvin and Shimek believed that these remains were of animals which were living during the time of deposition of the gravels, which they interpreted as Aftonian and interglacial. But if the sands and gravels are lenses and irregularly shaped pockets related in age to the till with which they are associated, then a somewhat different interpretation of the age of the mammals becomes necessary. At the present time it is impossible to state whether the gravels in which the mammalian remains have been found are associated with Nebraskan till or with Kansan till since, as stated above, it has not been possible thus far to differentiate Nebraskan till from Kansan till except where the relationships of the till to gumbotil the age of which is known have been established. If the gravels in which the mammalian remains have been found should prove to be lenses and pockets in Nebraskan till then the evidence would suggest that the animals are Nebraskan in age. It would be reasonable to assume that the animals were living in front of the Nebraskan ice sheet, which

was sometimes advancing and sometimes retreating and out from which sands and gravels were being carried. Remains of mammals became imbedded in the sands and gravels, which themselves later were overriden by or became incorporated in the onward moving Nebraskan till. If, on the other hand, the sands and gravels containing the mammalian remains should prove to be lenses and pockets in Kansan till then the suggested interpretation would be that the mammals were living on the Aftonian surface during the advance of the Kansan ice sheet, out from which sands and gravels were being carried. After remains of mammals became imbedded in these sands and gravels, the Kansan ice sheet, which was sometimes advancing and sometimes retreating, incorporated in the Kansan till these masses of sands and gravels in which the remains are found. If these conclusions are justified, then this mammalian fauna may not be a strictly interglacial fauna of Aftonian age. It is important to note, however, that the fauna is certainly early Pleistocene—that is, it was closely associated either with the advance of the Nebraskan ice or with the advance of the Kansan ice or with both as a result of having persisted on the adjacent plains from Nebraskan through Aftonian to Kansan time.

Mammalian remains in the gravels do not of themselves determine whether the gravels are strictly interglacial in age or are of glacial origin, as vertebrate paleontologists are not in agreement regarding the climatic conditions under which mammals such as have been found in these gravels may live. Dr. O. P. Hay[4] is of the opinion that the mammals the remains of which have been found in the gravels of western Iowa could not have lived in the immediate vicinity of an ice sheet, but must have lived under interglacial climatic conditions. On the other hand, W. D. Matthew[5] believes that in determining the age of gravels and sands stratigraphic evidence can be more safely followed than fossil evidence. In a letter he stated:

"What actually seems to have happened in the Pleistocene was that glacial advances drove the boreal forms southward and compelled them to mingle temporarily with temperate faunas. . . . When the retreat of the ice opened up northern territory again, the boreal types were the

4 Hay, O. P., The Pleistocene of the Middle Region of North America and its Vertebrated Animals: Carnegie Institution of Washington, Publication 322A, 1924.

5 Personal communication.

first to extend their range northward, and then or later retreated from the southern territory they had invaded.''

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

AFTONIAN PEAT DEPOSITS IN WESTERN IOWA

At only a few places in Iowa are there known peat exposures in which the relations of the Nebraskan till to the Kansan till can

FIG. 39.—The Dodge township, Union county, peat bed.

now be clearly established. Only three good peat exposures are known in western Iowa, two of them in Union county and the third in Crawford county.

One of the peat exposures in Union county is in the southeast part of section 36, Dodge township (T. 73 N., R. 29 W.), and the other is in a road cut one-half mile west of Thayer station in Jones township. The Dodge township peat bed, figure 39, was described in 1904 by T. E. Savage.[6] Beneath the peat is Nebraskan till, and above the peat is Kansan till. The Nebraskan till is

6 Savage, T. E., A Buried peat bed in Dodge township, Union county: Proc. Iowa Acad. Sci., Vol. XI, pp. 103-109, 1904.

unleached and is drab to dark gray in color where unoxidized and yellowish to brownish where oxidized. When dry it breaks into irregularly shaped fragments, when moist it is slightly flexible. The chief kinds of rock in the Nebraskan till are granites and greenstones, some boulders of which are a foot in diameter; limestones, quartzites, schists, and cherts also are present. In the Nebraskan till are some irregularly shaped sand pockets. The Kansan till above the peat has characteristics similar to those of the Nebraskan till. The elevation of the peat is about 1130 feet above sea level, or more than thirty feet lower than the nearest known outcrop of Nebraskan gumbotil, which is about one-half mile to the south of the peat deposit. The evidence indicates that where the peat was developed there was a depression on the Nebraskan gumbotil plain.

The peat in the road-cut one-fourth mile west of Thayer station, Union county, was made available for study in 1927 in connection with extensive road grading. The peat where best exposed is in the base of the cut and on the north side of the road. When the cut was examined the peat could be seen extending about three yards along the base of the cut and rising a foot and a half above the gutter. The peaty zone grades horizontally into brown carbonaceous silts and sandy silts. Above the peat are gray silts with a maximum thickness of seven feet. Above the silts is till and sandy and gravelly till, the lower part of which is oxidized and highly calcareous while the upper part is oxidized and leached. This is Kansan till, which is widely distributed and well exposed in this vicinity. The peat exposure has an elevation of about 1100 feet, which is the approximate elevation of the upper surface of the extensive gravels in the famous Thayer pit, which is less than one mile south of this peat bed. The evidence indicates that the gravels beneath Kansan till in the Thayer pit are lower topographically than the peat, which is in turn lower than outcrops of Nebraskan gumbotil in road cuts east of Thayer. The peat bed is Aftonian in age and the gravels in the Thayer pit are interpreted to be Nebraskan in age as they lie below the extension of the Nebraskan gumbotil plain, on the surface of which the peat was developed. The Nebraskan gumbotil and the peat are at the Aftonian stratigraphic horizon.

The peat deposit in Crawford county is in the slope of a small valley about two hundred yards southwest of the intersection of sections 13, 14, 23 and 24, Soldier township (T. 85 N., R. 41 W.). Here the section is as follows:

		Feet
5.	Loess, buff colored	4
4.	Till, Kansan, in part oxidized, and in part unoxidized and gray colored, unleached, pebbly	16
3.	Peat or lignite, Aftonian, consolidated into distinct layers	1½
2.	Silts, Aftonian, dark gray to drab, highly calcareous except in upper one foot where leached, many shells in the unleached part	7
1.	Till, Nebraskan, unoxidized and unleached except locally slightly oxidized; gray to bluish color where unoxidized, many concretions. To bed of stream	3

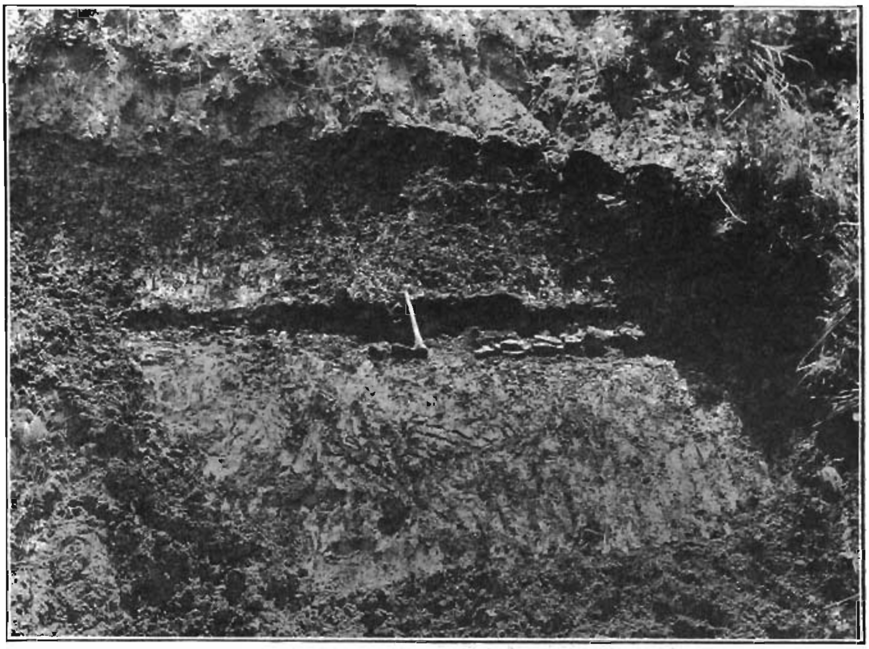

Fig. 40.—Aftonian peat in Soldier township, Crawford county.

The peat, figure 40, is exposed along the slope for more than twenty yards at an elevation of about 1355 feet above sea level. In the northwest quarter of section 20, Morgan township (T. 85 N., R. 40 W.), about two miles east of the peat, there is a section of Nebraskan till overlain by Nebraskan gumbotil at an elevation only about ten feet higher than that of the peat. This indicates that the peat was developed in a slight depression on the Nebraskan gumbotil plain. The section showing the Nebraskan gumbotil is as follows:

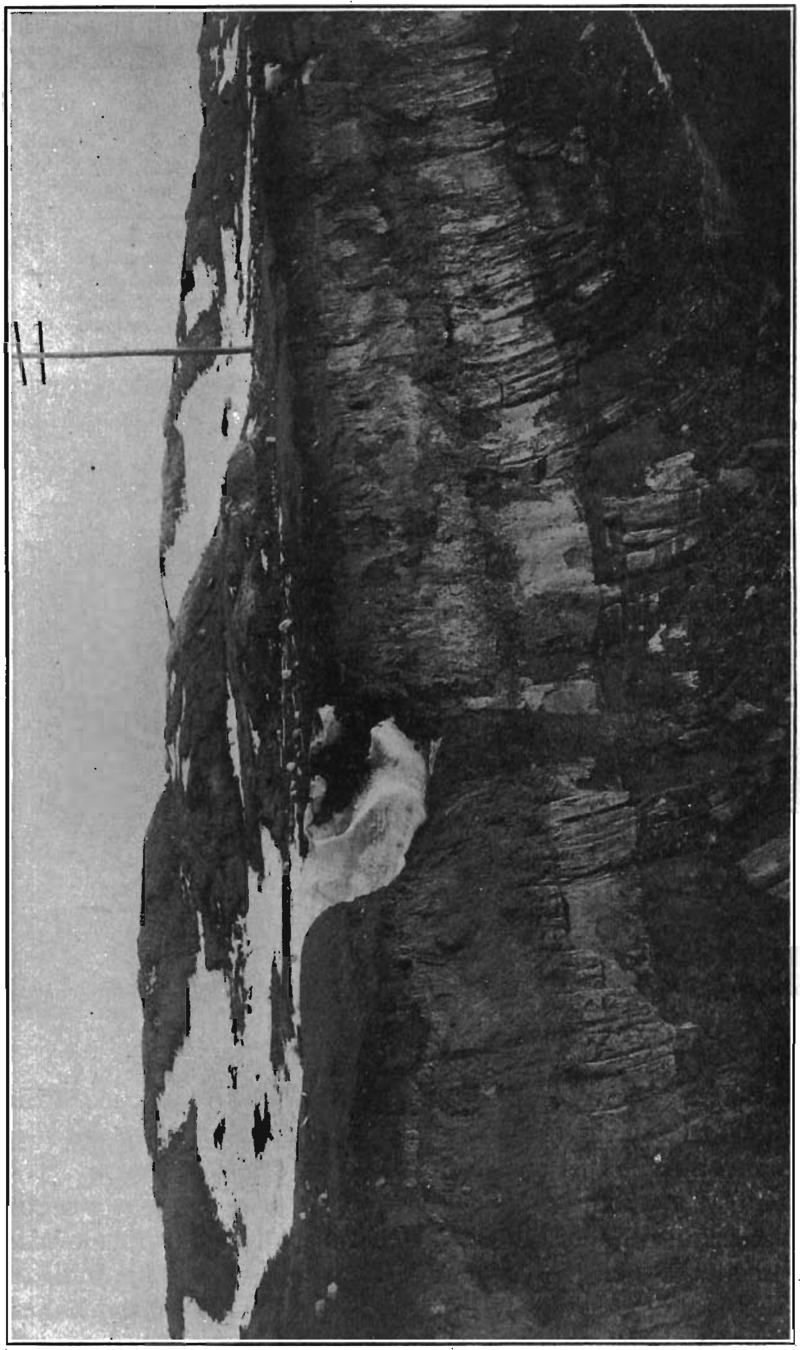

FIG. 41.—Oelwein cut showing Iowan till, Kansan till and Aftonian peat.

		FEET
4.	Loess	3+
3.	Till, Kansan, upper part oxidized, pebbly, lower part gray and unoxidized and unleached	5
2.	Gumbotil, Nebraskan, gray on dry surface, dark to drab on moist surface, concretions, few pebbles, leached, dark organic material in upper two feet	8
1.	Till, Nebraskan, oxidized, brownish gray where least oxidized, unleached	5

Sections representing the Aftonian in eastern Iowa

PEAT DEPOSITS AND SOILS IN EASTERN IOWA

The occurrence of peaty material and soil beneath the Kansan drift in eastern Iowa has been noted at several places. An exposure showing peat, as illustrated in figures 41 and 42, with Nebraskan till below and Kansan till above was available for study many years ago but is now slumped. This railway cut, long known as the Oelwein cut, created much interest among students of glacial deposits. It was just southeast of Oelwein in Fayette county on the Chicago Great Western railway in sections 27 and 28, Jefferson township (T. 91 N., R. 9 W.). The section as given by Beyer[7] is as follows:

FIG. 42.—Oelwein cut showing Aftonian peat below Kansan till.

[7] Beyer, S. W., Evidence of a sub-Aftonian till sheet in northeastern Iowa: Proc. Iowa Acad. Sci., Vol. IV, pp. 58-62, 1897.

		FEET
5.	Boulder clay, rather dull yellow in color; the upper portion is modified into a thin soil layer. Large boulders, mainly of the granitic type, are present, often resting on or partly imbedded in the deposits lower in the series. (Iowan)	0-10
4.	Sand and gravel—not a continuous deposit; often shows water action expressed in parallel stratification lines and false bedding. The gravels are usually highly oxidized and fine textured. (Buchanan)	0- 2
3.	Till, usually bright yellow above, graduating below into a gray-blue when dry or a dull blue when wet. This deposit is massive and exhibits a tendency to joint when exposed. Decayed granitic boulders are common. (Kansan)	3-20
2.	a) Sand, fine, white, well water-worn; often with a slight admixture of silt and clay. (Aftonian)	0- ½
	b) Vegetal layer and soil, from two to four inches of almost pure carbonaceous matter, with one to three feet highly charged with humus. The peaty layer often affords specimens of moss (Hypnum) perfectly preserved. (Aftonian)	0- 4
1.	Till, greenish blue when wet or gray-blue with a greenish cast when dry. Greenstones and vein quartz pebbles predominate. (Sub-Aftonian or Albertan). Exposed	10

The sub-Aftonian or Albertan till is the Nebraskan till of the present. Macbride[8] described the vegetal material as follows:

"It is a little surprising to find the lowest, that is, the oldest part of the bed, exhibiting organic objects in most perfect condition. The bottom of the seam is a compact mass of moss, compacted and pressed together no doubt, but absolutely untouched by putrefaction or decay, perfect in every leaf and fibre as any herbarium specimen in the world. Specimens you may examine show this perfectly. You may see the stem, the attachment of the leaves, the innovations, the form of each leaf, nay, the very areolation of leaf apex and base, quite as absolutely defined as in the case of any freshest specimen one may bring in now from any living turf or forest bed. For this reason we are able with much confidence to identify the species concerned although, so far, we have seen no smallest sign of capsule or fruit. So far, also, all the material seems to represent but a single species, a *Hypnum*, probably *Hypnum fluitans* Linn., a common moss which creeps out from shore or clings to floating objects, itself immersed or semi-floating in ponds, marshes or peat-bogs around the whole northern world.

Above the compacted moss which altogether makes up an inch or two of solid matter, lies a still more solid mass of vegetable detritus several inches thick. In this case the vegetation, whatever it was, appears to have undergone pretty thorough decomposition and disintegration before it was compacted. The microscope reveals simply cells and fragments of cells with considerable admixture of sharp, white sand, but nothing identifiable. This pulpy layer blends rather abruptly with a crude ad-

8 Macbride, T. H., A pre-Kansan peat bed: Proc. Iowa Acad. Sci., Vol. IV, pp. 63-66, 1897.

mixture of sand, mud and fragmentary vegetable detritus which, as said, becomes at length indistinguishable from the overlying drift.

In the lowest portion of the (upper) drift, and often resting directly on the peat seam proper, are quantities of half-decomposed wood, not rotten wood at all, rather wood which has lost its lignin and of which only the cellulose basis remains, but showing all the original structure elements and features with perfection absolute. The wood seems identical with that of *Larix americana*, Mx."

Alden and Leighton[9] redescribed this cut in their report on the Iowan drift. The interpretation of the materials was not altered after their study of the sections available in 1915. Leighton[10] in 1916 described a very complete section showing a thick soil zone between the Nebraskan and Kansan drifts. The location of this section is at the second viaduct one-half mile east of Delmar Junction in Clinton county. The section given by Leighton is as follows:

	Feet
Loess	
7. Loess, 1 foot of soil at top, grading below into brownish yellow to buff loess, wholly leached of calcareous material, mantles the eroded surface of the Kansan drift; thickness at the summit	8-10
Kansan Drift	
6. Ferretto zone at the top of the till, absent from the slopes, reddish brown, leached, pebbles show considerable decomposition; thickness	0- 1½
Grades downward into:	
5. Till, brownish yellow to yellow, summit rounded, leached of calcareous matrix and limestone pebbles in uppermost 7 to 8 ft., calcareous below with lime concretions and limestone pebbles, insoluble drift pebbles present throughout, lime concretions most abundant just below the base of the leached portion; maximum thickness	25
Grades downward into:	
4. Till, blue-gray or slate-colored, containing two large sand pockets, *a* and *b*, which have the appearance of included bodies, sand pocket *a* lies in the transition zone of (4) and (5), matrix of till calcareous and limestone and other drift pebbles present, fragments of wood in the basal portion, fills an old depression; thickness	0-28
Aftonian Soil	
3. Old black soil, with many small fragments of wood mineralized with iron pyrite, pebbles rare, some imperfectly laminated clay, soil-zone delineates an old depression with slopes as high as 12°. At an old track level is a stump with roots and rootlets running through the old soil and underlying clay; the wood is mineralized like the fragments of wood throughout the soil zone. Thickness of soil zone	2½- 3
Grades downward into:	
Sub-Aftonian Till	
2. Till, dark bluish green on damp surface, light grayish green	

9 Alden, W. C., and Leighton, M. M., The Iowan Drift: Iowa Geological Survey, Vol. XXVI, pp. 202-208, 1917.

10 Leighton, M. M., Superposition of Kansan drift on sub-Aftonian drift in eastern Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, pp. 133-139, 1916.

where dry, leached of calcareous matrix and limestone pebbles, but other drift pebbles are present; thickness .... 6+
Grades downward into:
1. Till, yellowish to brownish green, with some maroon-colored material in the lower part, leached 2 to 4 feet, calcareous below; thickness exposed 0-14

Another exposure of Aftonian vegetal material was found by Kay in 1916, in the western part of section 28, Washington township (T. 68 N., R. 4 W.), Lee county. The section has been described in detail in the discussion of the Nebraskan drift in southeastern Iowa, page 150. Leached sands and silts which included carbonaceous matter, sticks, and small logs constitute the Aftonian horizon, which is found between unleached and unoxidized Kansan till and Nebraskan till. Figure 43 is a photograph of this section.

WEATHERED GRAVELS IN EASTERN IOWA

When the Nebraskan ice sheet was retreating sands and grav-

FIG. 43.—Leached sands and silts with carbonaceous material and wood of Aftonian age. Lee county.

els were deposited in places on the ground moraine till plain. During Aftonian interglacial time these sands and gravels underwent weathering comparable in degree to the weathering changes which in the till produced gumbotil. At the same topographic position as the remnants of the Nebraskan gumbotil there are found sands and gravels which are thoroughly oxidized and leached to depths of more than 20 feet. Because of the greater porosity and permeability of sands and gravels in comparison with till the depth of weathering in the sands and gravels is greater than the depth of formation of Nebraskan gumbotil from till.

An exposure of much weathered sands and gravels showing alteration which took place in Aftonian time is in the extreme southeast corner of section 36, Iowa township (T. 77 N., R. 6 W.), Washington county. Schoewe[11] described the section as follows:

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

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

"The sands, which are highly oxidized and have a brownish color are fairly fine and have a low textural range. In structure they are highly contorted, dip at high angles, are crossbedded and at places, especially in the middle of the deposit, are more or less horizontal. A lens and pocket structure is conspicuous throughout the exposure in which occasionally leached mud or clay balls are found.

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

A second exposure showing the same sequence of materials was found a few miles southeast of the one just described, near

11 Schoewe, W. H., The Interpretation of Certain Leached Gravel Deposits in Louisa and Washington Counties, Iowa: Proc. Iowa Acad. Sci., Vol. XXVI, pp. 393-398; 1919.

the middle of the west side of section 8, Union township (T. 76 N., R. 5 W.), Louisa county.

Schoewe's discussion brings out the following points, from which his conclusions as stated below are derived:

1. The stratified sands and gravels are oxidized and leached.
2. These deposits lie between two fresh drifts of which the upper part of the overlying till is leached, hence presenting a section as follows:

Drift	leached
Drift	unleached
Sand and gravel deposit	leached
Drift	unleached

3. There are two such exposures, separated by several miles and having the same elevation as well as the same stratigraphic and topographic position.
4. The elevations of the sand and gravel deposits and the Nebraskan gumbotil in this area are approximately the same.

"The writer (Schoewe) is of the opinion that the lower drift is Nebraskan, that the sand and gravel deposits are Nebraskan outwash materials, that these outwash sands and gravels were oxidized and leached contemporaneously with the formation of the Nebraskan gumbotil and that the upper till is the Kansan."

Two exposures of Nebraskan gravels of the same type as those just described are found close enough to Nebraskan gumbotil so that their topographic position, and therefore their relationship to the Nebraskan gumbotil plain, may be determined. One of these sections has been described in the discussion of the Nebraskan drift in southeastern Iowa. It is located in an interurban railroad cut in the west side of Iowa river valley at Iowa City.

The second exposure is in a gravel pit in the northeast corner of section 17, Delaware township (T. 89 N., R. 5 W.), Delaware county. The gravels are highly oxidized and leached and associated with them is a sticky leached till. The level of the pit is below the tops of outcrops of rock near by. About one-eighth mile north of the gravels is Nebraskan gumbotil.

The Nebraskan Gumbotil

Aftonian time began with the uncovering of the ground moraine plain. Weathering agents at once began to change the till and related materials. The development of an oxidized phase of the till probably was rapid. The dissolved gases in meteoric waters together with the active compounds resulting from plant decay caused the more soluble constituents to be leached from the upper part of the oxidized till. This leaching was a slow process, the resulting leached zone being very limited in thickness in comparison with the depth of oxidation. Continued weathering produced disintegration and decomposition of many of the more complex materials in the till. Feldspars and ferromagnesian minerals especially underwent profound changes and the end product of the alteration of the minerals was in many places a very fine-grained or colloidal clay which became a matrix enclosing the unaltered and less altered fragments left from the disintegration and decomposition. The final product of the weathering of the till was the gumbotil. Its development was slow but in depth kept fairly close pace with the leaching. The first few inches of gumbotil probably were formed relatively rapidly; the next few inches less rapidly because of the impervious overlying fine-grained material. The lower portion of the gumbotil undoubtedly was developed very slowly. As the gumbotil continued to develop, the descent of surface water was more and more retarded and thus leaching became less and less effective. The thicker the gumbotil, the slower was the rate of descent of the leached zone. The average thickness of nearly nine feet of gumbotil on the Nebraskan till represents an extremely long interglacial time.

The formation of the gumbotil from the unleached and unoxidized till took place under conditions of poor drainage. Therefore the ground moraine plain on which the gumbotil was formed must have persisted during the time the gumbotil was being developed. Where the relief of the surface was such that there was good drainage gumbotil did not develop, but the till became oxidized and leached unless erosion kept pace with the weathering. Theoretically it should be possible to find all gradations of material between unleached and unoxidized till, where erosion carried away the weathered material as rapidly as it was formed, and gumbotil, where the weathering was not accompanied by erosion. Before the close of Aftonian time the till plain upon which the gumbotil had been developed was extensively modified by erosion.

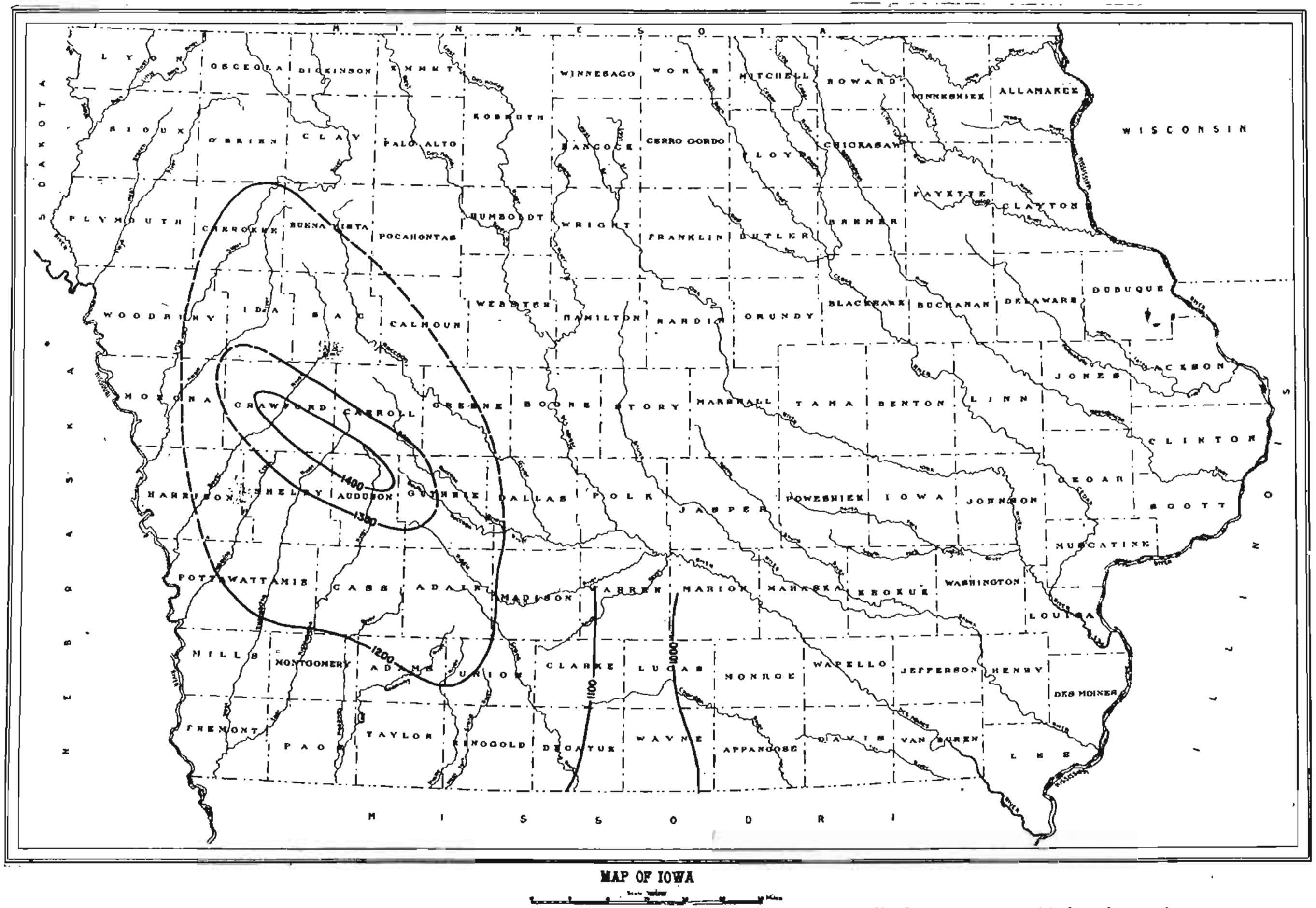

FIG. 44.—The altitudes of the Nebraskan gumbotil plain in western Iowa represented by generalized contours at 100 foot intervals.

In some places not only the gumbotil but all of the Nebraskan till was carried away; in other places in the state a considerable part of the gumbotil plain was not eroded; in still other places only remnants of the gumbotil plain were left intact at the close of Aftonian time. The amount of dissection differed greatly in different parts of the state.

The Nebraskan gumbotil, where it is now found, marks the position of the surface of the plain on which the material was formed (see figure 26). It is possible to reconstruct the plain over areas where the outcrops of the gumbotil are numerous and to construct for larger areas a map to show the attitude of the till surface during Aftonian time. Figure 44 is a contour map of a part of the state drawn with an interval of 100 feet to show the present altitude of the Nebraskan till plain on which the gumbotil was formed, and therefore the present altitude of the Aftonian surface.

Aftonian Erosion

The sheet of drift left over the bed rock by the first ice sheet had, at least over large areas, a nearly level plain surface. On this plain gumbotil developed under conditions of poor drainage. The formation of the gumbotil was interrupted by the drainage of the plain on which the material was developing, but the interruption was sufficiently long delayed so that more than eight feet, on the average, of gumbotil was formed. The erosion which began with the development of the drainage systems which interrupted the formation of the gumbotil continued for a long period of time. Valleys were cut in the Nebraskan drift and into the bedrock beneath the drift. The bedrock in the northeastern corner of the state was dissected by valleys deepened 400 feet or more during interglacial time. The widening of the valleys in the drift cut away much of the gumbotil plain, especially in the eastern part of Iowa, where the influence of Mississippi river was felt through the steep gradients of the tributaries. But with increase in distance from Mississippi river the remnants of the Nebraskan gumbotil plain are more and more widely represented, until in Adams and Taylor counties in southwestern Iowa the gumbotil plain seems to have been dissected but little before the coming of the Kansan ice sheet. Some parts of the gumbotil plain were left almost intact and between such areas and those of extreme dissection there was represented almost every stage of land reduction by erosion.

The relief over most of the state at the end of the interglacial stage probably averaged less in amount than that at the beginning of the Pleistocene, though locally it was as great or greater. The surface was rough and rugged when the Kansan ice advanced over it. The difficulties in distinguishing between the less weathered Nebraskan drift below the gumbotil and the Kansan drift which may rest upon it on the pre-Kansan valley slopes have made it impossible to determine even approximately through the study of the amount of valley filling by the Kansan drift the depth of the valleys cut in the Nebraskan drift by the streams of Aftonian time. It is possible, however, by using the bottoms of the steep sided sharp valleys described in Chapter I as of Aftonian age, to determine the approximate level of stream erosion in certain areas. Where these rock-bound buried valleys are found there are but few outcrops of the gumbotil, but from the few which are known, the depth of Aftonian erosion below the gumbotil surface is indicated as having been locally as great as 400 feet or perhaps somewhat more, though figures of 200 feet or less are the most common.

Aftonian Loess

The presence of loess on the surface of the Nebraskan drift and beneath the Kansan drift is to be expected. There are, however, but few places in which evidence of this æolian deposit of Aftonian age has been found. The most extensive exposure of possible Aftonian loess is that along the road east of Inwood, Lyon county, in section 16, Lyon township (T. 98 N., R. 48 W.), the complete section of which has been described in the discussion of the Nebraskan drift in northwestern Iowa (page 160). Here beneath Kansan till are found thirty feet of silts, some of them light buff in color, very fine in texture, with concretions like those in the loess, and with a loesslike feel. It is probable that several feet of the silts represents Aftonian loess.

A second exposure of silts which may be in part Aftonian loess is found a short distance west of the village of Thayer, Union county, in section 22, Jones township (T. 72 N., R. 28 W.). The horizon represents the Aftonian as the silts are leached, are associated with peat, and are overlain by highly calcareous gravels and till. There is considerable carbonaceous matter mixed with the fine material, especially in the upper part. A maximum thickness of seven feet of the silts was exposed at the time of making the section which is described in detail in the discussion of the Aftonian peat deposits of western Iowa, page 196.

Aftonian material of loesslike character lies between Nebraskan gumbotil and Kansan till in a road-cut between sections 18 and 19, Jackson township (T. 79 N., R. 37 W.), Shelby county. A road cut through the crest of a ridge showed the Nebraskan gumbotil extending as a band for a distance of 70 yards across the face of the cut on each side of the road. The upper surface of the gumbotil was uneven because of ploughing by the overriding Kansan ice and because of pre-Kansan erosion which had removed part of the gumbotil. Mantling the pre-Kansan erosion surface on the gumbotil is a gray silty clay, loesslike, ranging from a few inches to over a foot in thickness, with layers set apart by accumulations of blackish carbonaceous matter. The fine texture of this silt, the fact that it mantles an uneven surface of the gumbotil, its inclusion of carbonaceous matter between layers, and the absence of distinct stratification suggest that it is of the same origin as the younger loesses, and is therefore an Aftonian loess.

The Record of Life in the Aftonian

The record of Aftonian life in Iowa is not extensive. The sands and gravels from which animal remains have been secured are not, in most cases, identifiable as to age. Many of the gravel deposits appear to be Nebraskan in age and therefore fossils from them would represent early Nebraskan life. The outwash materials from the ice overloaded the streams, causing them to aggrade their beds with the sands and gravels carried by the glacial waters. Into the same beds were swept invertebrate remains from the valley sides and from the scoured parts of the stream channel. There were also carried in such remains of vertebrate animals as were left within reach of the flood waters from the ice. The accumulation of glacial débris and vertebrate and invertebrate animal remains constitutes the deposits formerly called Aftonian but now thought to be more specifically glacial in origin. Whether these gravel and sand deposits were picked up by the ice and incorporated as masses within the till or were overriden by the ice and covered with till makes little difference as to their age.

Because the Kansan glacier formed deposits of the same character as those described above, and because these deposits cannot at present be differentiated from the Nebraskan sand and gravel deposits in western Iowa where only the Nebraskan and Kansan drifts are present, the age of any particular deposit is indeterminate. None of the deposits associated with the till, however, can be younger than Kansan, and any remains of animals must be those of early Kansan age or older.

The age of the faunas represented by the fossils in the gravels which have been called Aftonian is as follows: The gravels and sands associated with the Nebraskan drift will carry a fauna which is pre-Nebraskan in age, and therefore of very early Pleistocene age. These forms should be more closely related to the Pliocene forms than to later forms as the next record in this state would be of those animals which had emigrated during a great glacial invasion and then returned, perhaps with different associates, after the retreat of the ice.

The fossils found in the sands and gravels associated with the Kansan till represent a fauna of Aftonian age. They would be the remains of forms whose ancestors lived during the Aftonian, but of individuals which lived in early Kansan time.

Aftonian life should, ideally, be recorded in fossils in strictly interglacial deposits. Such deposits have rarely been found. Some of the peat deposits of Aftonian age contain identifiable plants, and some silts underlying the peats have molluscan faunas. Also wood in the base of the Kansan drift represents late Aftonian growth. Vertebrates which are definitely of Aftonian age have been found but rarely in this state. As was stated above, it is believed, from stratigraphic evidence, that most of the vertebrate forms described as Aftonian in age are in reality from gravels and sands of early Nebraskan age and therefore represent forms more closely related to the Pliocene than to the Aftonian.

The specific forms of life represented by fossils from this early part of the Pleistocene will not be discussed. Two very excellent summaries of the Pleistocene life of Iowa have appeared in late years. One, by O. P. Hay[12] on the Pleistocene of the Middle Region of North America, catalogs the vertebrate forms which have been collected from Pleistocene deposits of all ages in Iowa, and reviews the available data regarding the ages of the remains. The authors, as Doctor Hay states, are not in agreement with his interpretation of the age of the deposits in which the so-called Aftonian remains have been found. The interpretation offered above only makes the possible age of the oldest fossiliferous Pleistocene gravels still earlier than Aftonian, and the age of none very much later than the close of that interglacial interval.

The second comprehensive review of the forms of life represented from the early Pleistocene of Iowa is by F. C. Baker.[13] Faunal lists are given, with a brief discussion of some of the deposits from which the remains have been secured, but references to the sources from which the lists have been compiled are quite complete. The lists include both vertebrate and invertebrate forms. No new data are added on the life of the interglacial epochs in Iowa in addition to what have appeared in the publications cited.

12 Hay, O. P., The Pleistocene of the Middle Region of North America and its Vertebrated Animals: Carnegie Institution of Washington, Pub. 322A, 1924.

13 Baker, F. C., The Life of the Pleistocene or Glacial Period: University of Illinois. 1920.

CHAPTER VI

THE KANSAN GLACIAL STAGE

The Kansan glacial stage followed the Aftonian interglacial stage and is the second of the five glacial stages now recognized in the Pleistocene of Iowa. The name Kansan was given by Chamberlin in 1894 to the older of two drifts in the Afton Junction-Thayer region in Union county, Iowa. At that time the younger of the two drifts there was named East Iowan. Chamberlin believed that the two tills named Kansan and East Iowan were of the same ages as McGee's Lower Till and Upper Till respectively, which had been mapped areally in northeastern Iowa. Later, for reasons given in Chapter III of this report, which deals with the history of investigations and classifications of the Pleistocene deposits of Iowa, the name Kansan was shifted to the upper till of the Afton Junction region and the lower till there was then named Sub-Aftonian or Pre-Kansan till, a name which was continued until 1909 when it was given the name Nebraskan till. The name Kansan has had its present usage since 1896.

Discrimination of the Kansan Drift

The Kansan drift is a stratigraphic unit in the unconsolidated Pleistocene deposits of North America. Stratigraphic methods determine it to be a drift widespread in distribution, of definite age, and bearing certain consistent relationships to deposits both older and younger. It is composed of characteristic glacial till, with associated sands and gravels, which occur either as included masses or as channel or wash deposits on the surface of or within the till.

Stratigraphically, the Kansan drift is limited below by Nebraskan drift or by Aftonian deposits or by indurated rocks, and above by younger Pleistocene deposits or the present soil surface. Any phase of the Kansan drift except the gumbotil phase may be found in contact at its base with any one of the following deposits:

- Aftonian deposits
  - sand
  - gravel
  - soil
  - peat
  - loess
- Nebraskan drift
  - gumbotil
  - oxidized and leached till
  - oxidized and unleached till
  - unoxidized and unleached till
  - weathered or unweathered sands and gravels
- Indurated rocks
- Residual products of rock decay

Above the Kansan drift and in contact with it may be found any one of the several deposits which constitute the depositional record of the Yarmouth, Sangamon, or Peorian interglacial stages, or of the Illinoian, Iowan, or Wisconsin glacial stages, or of Post-Wisconsin time.

The discrimination of the Kansan drift is rendered simple when that drift is found between Pleistocene materials known to represent the Nebraskan or the Aftonian below and the Yarmouth or the Illinoian above. These relationships are found in the sections in Washington and Denmark townships, Lee county, which have been described on pages 148 to 151. Such relationships are observed rarely and it is necessary therefore to apply other criteria for the recognition of Kansan deposits.

In the sections described in Washington and Denmark townships on page 148 there are three drifts. The lowest drift with a secondary profile developed from a former gumbotil, has above it a drift topped with gumbotil and related materials on top of which is a third drift, also gumbotil-covered in the vicinity. Only three drifts have been found on which gumbotil has been developed, and these three are the Nebraskan, the Kansan, and the Illinoian, all three of which are present in southeastern Iowa.

In tracing the two upper gumbotil-covered drifts westward from Mississippi river the upper gumbotil is found to be limited to the area defined by Leverett[1] as within the boundaries of the Illinoian drift. Beyond the limits of the Illinoian, the Kansan gumbotil becomes the top feature of the drift. Here, where the top of the Kansan drift has not been disturbed by erosion, it forms a plain. Where erosion has dissected the plain in southeastern Iowa there are remnants as extensive as the major portions of the interstream areas. The finding of isolated gumbotil exposures with elevations closely in accord with the general level of the projected surface of this gumbotil plain is recognized as a basis for the identification of the gumbotil and the till immediately beneath it as Kansan. The extremely satisfactory use of this criterion in southern Iowa has led to its being used beyond that portion of the state and thereby has permitted the working out of Pleistocene history more definitely than had been possible previously.

The Kansan gumbotil plain may be traced from exposures in southeastern Iowa westward to exposures only a few miles from Missouri river (see figure 27). Over a major part of this distance the dissection of the plain has been so great that the Nebraskan drift with its gumbotil has been exposed in many sections (see figure 26). As only the two oldest drifts of the Pleistocene are present in this area, where a gumbotil is found with a till above it the gumbotil is pronounced Nebraskan and the till above it Kansan. Where a gumbotil is found with no till above it, and it occupies a place high on extensive divides, the probability is that it is Kansan. This in most places can be checked by its agreement in elevation with neighboring gumbotil exposures of Kansan age which are determined from their relations to the Nebraskan gumbotil.

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1 Leverett, Frank, The Illinois Glacial Lobe: U. S. G. S. Monograph 38, 1899.

In the extreme northeastern part of the state stream erosion during Aftonian time cut deep valleys through the Nebraskan drift and into the bedrock beneath. The Kansan drift fills to the bottom the upper parts of many of these valleys and in this later filling the streams have only partly intrenched themselves. The Nebraskan drift, from its topographic position high on the sides of the stream valleys only, is recognized as older than that drift which fills the valleys to their bottoms. The Iowan drift surface is found a few miles west of the edge of the Kansan drift. The Kansan drift is known to be older than the Iowan because it has suffered dissection which is very markedly greater than that which even the margins of the Iowan have experienced. The Kansan drift itself shows leaching to a greater depth and a much more advanced degree of oxidation—it looks older—than the Iowan. A secondary feature useful in the field for distinguishing between the Iowan and Kansan drifts is the presence of relatively thick loess over the dissected Kansan at the margin of the Iowan while the Iowan drift itself is but lightly mantled by the windblown material. That the thick loess-covered drift at the margin of the Iowan is not the Illinoian seems certain. The known Illinoian drift is from the Labrador center of ice dispersion, and this drift is from the Keewatin center. This drift is more dissected than the Illinoian though it has been in about an equivalent position with respect to the drainage lines crossing it. Also, the Kansan drift has been traced by means of the gumbotil under the Iowan drift into nearly all parts of the Iowan area, and this is the only drift which is extensively known under the Iowan. It seems therefore that present interpretation should follow custom and designate this older drift to the east of the Iowan area as the Kansan.

Distribution of the Kansan Drift in Iowa

The presence of the Kansan gumbotil has made it possible to identify the Kansan drift over the southern third of the state. This formation may be traced from the Missouri line northward into Iowa for a distance of more than 70 miles and within this area it may be traced eastward within five miles of Mississippi river and westward within about the same distance from Missouri river. Within this area the Kansan gumbotil plain shows a remarkably persistent uniformity of surface, spreading from divide to divide through a series of slight but regular changes in elevation. The presence of the Kansan in this area is certain and definite.

The Kansan drift may be traced northward along Mississippi river to the vicinity of Bellevue, Jackson county. The margin here leaves the river and extends in an irregular sweeping line to a point on the Minnesota boundary about 50 miles west from Mississippi river. To the east of this border the only deposits of Pleistocene age that have been found are loess, valley gravels and upland patches of Nebraskan drift. West of the Kansan drift boundary Kansan drift fills rock gorges, crowns the uplands and has been carved into a rugged mature topography. No gumbotil has been found here, but the drift surface is overlain by a relatively thick loess which may obscure gumbotil on this part of the Kansan if it is present.

The border zone of the Kansan drift north of Bellevue, just described, is only a few miles in width, this surface being replaced to the west by a much younger topography. The reason for this topography is found in numerous places where a gumbotil is overlain by a young drift, the Iowan. The gumbotil exposures beneath the Iowan are limited in number, but the character of the gumbotil, its thickness, and its elevation from place to place permit its being traced as an horizon westward to the Wisconsin moraine and south beneath the Iowan drift to the Kansan drift of the tabular divide area in the southern part of the state.

In central Iowa, where the thick Wisconsin drift forms the surface, few exposures of gumbotil or of drift older than the Wisconsin have been found. Some of these are definitely Kansan in age.

The Kansan till may be traced into northwestern Iowa by means of the gumbotil at its surface as far north as northern Crawford county. The absence of Kansan gumbotil farther to the north in northwestern Iowa was explained in a former part of this paper as being the result of erosion of the Kansan gumbotil after it had been developed here as well as in other parts of the state.[2] In northwestern Iowa the Kansan drift overlies Nebraskan gumbotil and Nebraskan till and, in Lyon county, silts, which separate it from the Nebraskan till below. As has been stated previously, there are local areas in northwestern Iowa where the Kansan and Nebraskan tills may be distinguished by their lithologic differences, even where only one of the tills is present.

The second glaciation of the Pleistocene, as judged from the distribution of ice deposited materials, covered all of Iowa except a small area in the form of a narrow strip along Mississippi river in the northeastern part of the state.

Origin of the Drift

The Kansan drift is typical of glacially borne materials, with boulder clay, or till, making up the greater part of the formation and with sands and gravels associated with the till. The ice sheet which carried this drift into and over Iowa did not have the same foundation over which to move as did the Nebraskan glacier. The first glacier advanced over a deeply weathered surface with much loose material and with rock cored hills and rock walled valleys. The Kansan ice sheet moved over a surface which was largely the product of the erosion of a glacial drift plain. The surface slopes could not have been steep nor the valleys cliff-bound except where the streams had cut through the Nebraskan drift and into the rock beneath. The surface was covered with much loose material, but this was of glacial origin rather than from the secular decay of the indurated rocks. There was probably much more load to be easily acquired by the Kansan ice than by the first ice sheet, which tended to reduce the amount of freshly eroded material added by the Kansan ice to the glacial débris which was to form the surface of the land when the ice melted.

The evidence of the acquisition of material by the Kansan ice from the underlying Nebraskan drift is direct. The top of the Nebraskan gumbotil shows an irregular surface in many sections because of the ploughing by the overriding ice. Among the

2 Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geological Survey, Vol. XXVI, pp. 213-231; 1917.
Carman, J. E., The Pleistocene geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXVI, pp. 332-334, 1917.

many sections where the irregular, ploughed surface appeared conspicuously are those located as follows:

West side of section 32, East Boyer township (T. 83 N., R. 38 W.), Crawford county.
East part of the line between sections 17 and 20, Jones township (T. 72 N., R. 28 W.), Union county.
Between sections 19 and 20, Liberty township (T. 69 N., R. 29 W.), Ringgold county.
In a road cut in section 20, Jackson township (T. 72 N., R. 23 W.), Lucas county.

At the location last named the Nebraskan gumbotil extends along the face of the cut for a hundred feet, but at the west end of the exposure the gumbotil has been entirely removed, evidently by the ploughing of the ice.

Another evidence of the acquisition of material from the underlying surface by the Kansan ice is to be found in the character of some of the inclusions in the Kansan drift.

A road cut along the north side of the northwest quarter of section 34, Douglas township (T. 72 N., R. 35 W.), Adams county, shows a number of inclusions in the Kansan drift. The elevation is only slightly above the Nebraskan gumbotil in this area, and the inclusions consist of irregularly shaped masses of sand and of Nebraskan gumbotil. To the east of this cut are others which show what appears to be a mixture of sand and gumbotil with the normal till materials.

The retreat from the land of the ice mass of Kansan time took place as did that of the former glaciation, by melting of the ice at the edge faster than it was being extended. As the area occupied by the ice was reduced it left more and more of the glacial bed covered with the unsorted and sorted materials which had been a part of the glacial mass. The streams flowing out from the melting ice worked over some of the till and left a portion of the sorted débris along the drainage channels. The glacial till and the sorted materials washed out of the till by streams flowing while the Kansan ice was still in existence constitute the drift of Kansan age, or the Kansan drift.

Changes in the Drift

The Kansan drift surface, when it was uncovered, was immediately subjected to the operation of the modifying agencies of weathering. Rain, air, and ground water began the work of altering the drift, first by oxidation and then by leaching, so that three zones were soon developed with the oxidized and leached till at the top, below which was an oxidized and unleached zone, beneath which was the fresh till as yet unchanged. The time during which the Kansan till was at the surface was long enough for the alteration of the till beyond the leached stage; in fact gumbotil was formed to an average depth of over eleven feet. Leaching advanced at such a rate that there is an average of about five and a half feet of leached till below the gumbotil, making a zone of about seventeen feet within which the alteration of the Kansan till has been very marked.

A complete, single section of the Nebraskan and Kansan drifts in contact is nowhere known. By piecing out from the observed sequences of the two drifts, the following section is known to obtain where all phases of the Nebraskan and Kansan are present:

Kansan gumbotil
Kansan oxidized and leached till
oxidized and unleached till
unoxidized and unleached till
Nebraskan gumbotil
Nebraskan oxidized and leached till
oxidized and unleached till
unoxidized and unleached till

This sequence is shown diagrammatically in figure 45.

Typical Sections of the Kansan Drift

KANSAN DRIFT IN THE KANSAN DRIFT AREA

The most complete section of Kansan till thus far seen in the state is on the south side of Cedar creek valley, south of Fairfield, along the middle of the line between section 24, Liberty township (T. 71 N., R. 10 W.), and section 19, Cedar township (T. 71 N., R. 9 W.), Jefferson county.* Between the town of Fairfield and this cut the Kansan gumbotil is seen along the road in several places where the loess has been cut through. The contact between the loess and the gumbotil is sharp in most places. The base of the gumbotil is seldom exposed in the shallow excavations which have been made, but at the location given

* The locations of these sections may be found on Plate I in the back of this report.

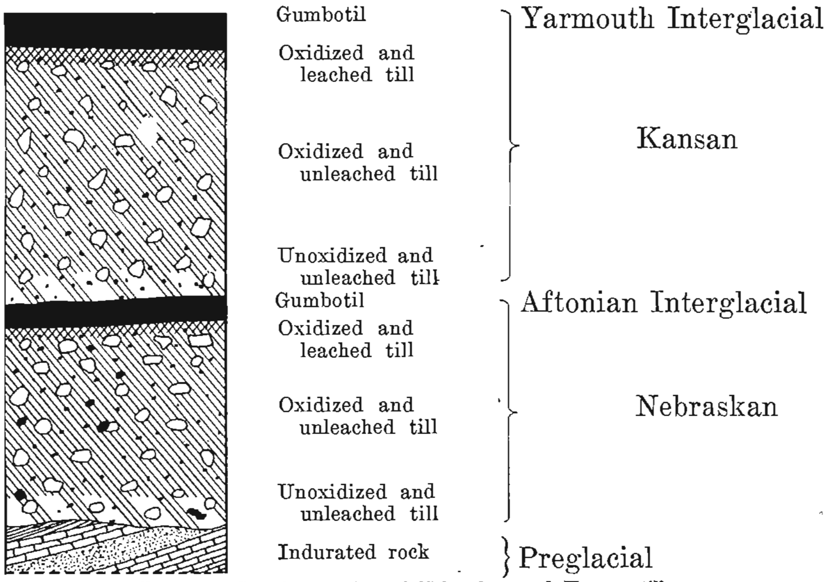

FIG. 45.—Complete section of Nebraskan and Kansan tills.

above the road out of the valley has been graded and the following section is exposed:

		FEET
7.	Loess, Peorian, heavy silty clay, color not uniform but basic color olive-gray; many angular granules, about ¼ inch in diameter and irregular in shape; much rusty brown dull material, which is chiefly in the interiors of the granules as inclusions; some black, soft to semihard ferruginous pellets; plastic and compact when wet, leached	9½
6.	Loess, Loveland, friable silt, shows worm casts, medium compact, few small pebbles, in lower part concentration of black iron oxide masses, mottled grayish yellow color, decidedly darker than base of upper loess	1½
5.	Gumbotil, Kansan, light gray to drab-colored when dry, darker when wet; upper part mottled with some brown material as though some of the loess had worked into it through root holes or the burrows of animals. Lower part interfingers with the zone below, making a gradational change between the two materials	12
4.	Till, Kansan, oxidized and leached; the upper part mostly gray, resembling the gumbotil; the mass is reddish buff, or brownish with small patches of lighter buff color and with more or less gray entirely through the zone. Fracture irregular, not controlled by joints when dry	5½
3.	Till, Kansan, oxidized and unleached, sandy; considerably lighter in color than the oxidized and leached zone above; mostly buff with some streaks of brownish color; largest rock fragment seen in this zone was 18 inches in diameter; very little change in color in whole depth of this zone	22½
2.	Till, Kansan, unoxidized and unleached; near a neutral gray when dry, but with a bluish tinge when wet and much darker than when	

dry; upper part occurs in masses surrounded by the oxidized till, then the oxidized till is restricted to stringers through the unoxidized till ... 12
1. Sandstone, interbedded with conglomerate, exposed about ... 6

Just north of Fairfield along primary road 1, at the Rock Island overhead bridge, on the west line of section 24, Center township (T. 72 N., R. 10 W.), Jefferson county, a road cut shows the relation of the gumbotil to the underlying Kansan till, as shown in figure 46.

FIG. 46.—Kansan gumbotil grading downward into Kansan till, in road cut just north of Fairfield, Jefferson county.

On the Sante Fe railroad east of New Boston (Bricker station on this railroad), in the east half of section 36, Charleston township (T. 67 N., R. 6 W.), Lee county, is a cut which exposed the following section:

		FEET
4.	Loess, leached, grayish buff to gray; this rises at the top of the cut to the level of a fine Kansan upland; in the cut	11
3.	Gumbotil, Kansan, drab-gray; few pebbles; no evidence of lamination or humus, and appears to be a unit in origin and to have been derived from the till below	12
2.	Till, Kansan, oxidized and leached, grades into the gumbotil	5½
1.	Till, Kansan, oxidized and unleached; has some concretions of secondary calcareous material	27

A photograph of this cut is shown in figure 47.

The cut described above is one of a series made along the Sante Fe railroad. Another cut just west of Bricker station showed the following sequence of materials:

		Feet
3.	Loess, leached	5½
2.	Gumbotil, Kansan	7
1.	Till, Kansan, oxidized and leached, upper part with some gray color; exposed	5

Fig. 47.—The New Boston section of Kansan drift in which Kansan gumbotil is present.

The till below the oxidized and leached zone was slumped and the lower limit of the leached till could not be determined accurately.

A quarter mile west of Bricker station still another cut showed two feet of Kansan gumbotil at the surface, with five and a half feet of oxidized and leached till and ten feet of oxidized and unleached till beneath. The materials all gave evidence of grading one into the other.

Not all of the cuts show the Kansan gumbotil for in places it was entirely removed by erosion before the deposition of the loess. Just east of the station the following section was exposed:

		Feet
3.	Loess, leached, resting on the basal part of the gumbotil	11
2.	Till, Kansan, oxidized and leached	5½
1.	Till, Kansan, oxidized and unleached, with some concretions from the material above	27

The following section was observed in section 29, Harrison township (T. 68 N., R. 7 W.), Lee county, on the east slope of Lick creek:

		Feet
4.	Loess, leached; grayish to grayish yellow on a dry surface; more yellowish to brownish when damp; mass traversed by irregular cracks; gummy when wet; no pebbles found; not sharply set off from the gumbotil below	7
3.	Gumbotil, Kansan, dark gray on dry surface, drab when wet; starchlike fracture, sticky when wet; breaks along irregularly directed and spaced joints when dry; a few siliceous pebbles; no concretions; grades into 2 below	4
2.	Till, Kansan, strongly oxidized and thoroughly leached; brownish yellow, with patches of gray in the upper part	5½
1.	Till, Kansan, oxidized and unleached; lighter in color than 2, being more a buff than brown; has concretions, exposed for several feet.	

In the south part of the line between sections 4 and 5, Center township (T. 69 N., R. 25 W.), Decatur county, there is an exposure of the base of the Kansan gumbotil and the zones below. The gradations between successive phases of the till are strikingly evident. A photograph, figure 48, shows the zones in this cut. The section is as follows:

		Feet
4.	Loess, leached, buff	3
3.	Gumbotil, Kansan	2
2.	Till, Kansan, oxidized and leached; upper part grading distinctly into the gumbotil	5½
1.	Till, Kansan, oxidized and unleached; many concretions, exposed	4

The section described below was seen in the northeast part of section 25, Franklin township (T. 75 N., R. 8 W.), Washington county. In this county the Kansan is typically developed and shows the constant, characteristic relationships between the various phases of the till which mark it all over the state. The section here showed:

		Feet
4.	Loess, Peorian, buff, leached to the upland	11
3.	Loesslike sandy clay, Loveland, light colored	1½
2.	Gumbotil, Kansan, drab below but becoming more red near the top; siliceous pebbles from top to bottom; surface shows characteristic polyhedral fracture; some concretions present in the gumbotil	9
1.	Till, Kansan, leached; exposed about	2

A short distance away the section was extended to show the following materials below the gumbotil:

FIG. 48.—A Kansan drift section in Decatur county showing loess, gumbotil, oxidized and leached till, and oxidized and unleached till with concretions.

1a.	Till, Kansan, oxidized and leached, grades above into the gumbotil	5½
1b.	Till, Kansan, oxidized and unleached; yellowish buff in color; numerous joints with concretions along them in the upper part; exposed for over	20

About one mile east of Foster, in section 19, Urbana township (T. 71 N., R. 16 W.), Monroe county, along the Chicago, Milwaukee, St. Paul & Pacific railway, is a cut which showed the following sequence of materials in descending order: loess, Kansan gumbotil, Kansan drift. The zones below the gumbotil are strongly oxidized to a brownish, in part almost a chocolate color. This cut was described in detail, and chemical analyses of the gumbotil and oxidized and leached till were reported in a paper by Kay and Pearce[3] on the origin of gumbotil.

Many exposures of the basal part of the Kansan drift have been described in the chapter on the Nebraskan, in connection with the occurrence of Nebraskan gumbotil. The sections which have been given are typical of many others which might be added from areas adjacent to those from which the exposures have been described.

KANSAN DRIFT UNDER THICK LOESS

Many of the best sections showing Kansan gumbotil are found under a greater or less thickness of other Pleistocene materials. The sections already given show loess in nearly every case, and a few will be given in which loess is still thicker over the gumbotil. Besides the loess as a covering of the gumbotil of Kansan age there are sections known in which the Illinoian till, the Iowan till, and the Wisconsin till each overlies a part of the Kansan gumbotil plain in the areas of those respective drifts. Sections typical of each relationship will be given.

Of the sections showing thick loess, the following are representative. In Clarke county, on the Chicago, Burlington & Quincy railway, one mile west of Murray, in section 9, Troy township (T. 72 N., R. 27 W.), the following section was found:

		Feet
4.	Loess, gray to pale yellowish color on dry surface with irregular lines of brown; when damp it is grayish with mottling of yellow to brown colors; stands vertically, upper few feet mealy	15
3.	Gumbotil, Kansan, gray to drab in color, sticky when wet, hard and tenacious when dry; contains a few siliceous pebbles; leached	11
2.	Till, Kansan, oxidized and leached	4
1.	Till, Kansan, oxidized and unleached; has many concretions	11

This section was described and chemical analyses of the till phases were reported in the paper by Kay and Pearce.*

Two miles south of Crawfordsville, in section 22, Crawford

[3] Kay, G. F., and Pearce, J. N., The Origin of Gumbotil: Jour. of Geology, Vol. XXVIII, pp. 89-125, 1920.

* Op. cit., pp. 95, 96.

township (T. 74 N., R. 6 W.), Washington county, the loess is still thicker as the section shows:

3.	Loess, to the upland	18
2.	Gumbotil, Kansan	8
1.	Till, Kansan, oxidized and leached above, grading down into oxidized and unleached	12

A cut on the Chicago, Milwaukee, St. Paul & Pacific railway through the high upland between the Mississippi river drainage and the Missouri river drainage, in section 13, Warren township (T. 82 N., R. 36 W.), about three miles west of Templeton, Carroll county, shows Kansan drift on which Kansan gumbotil has been developed to a thickness of 15 feet. This is the maximum thickness of Kansan gumbotil which has been found in the state. The section is as follows:

		Feet
5.	Loess, Peorian, buff colored, upper 15 feet leached	25
4.	Loess, Loveland, reddish to chocolate colored, leached	5½
3.	Gumbotil, Kansan, gray to dark drab to chocolate colored, upper few feet reddish, a few small siliceous pebbles	15
2.	Drift, Kansan, oxidized yellow to buff, leached, closely related to number 3	7
1.	Drift, Kansan, oxidized, unleached; many calcareous concretions	8

A cut along an old railroad grade in section 8, Keg Creek township (T. 74 N., R. 42 W.), Pottawattamie county, shows more than six feet of Kansan gumbotil overlain by loess, which in this area is about 90 feet thick.

KANSAN DRIFT UNDER ILLINOIAN DRIFT

In the area covered by the Illinoian drift there are numerous sections which show the Kansan drift below the Illinoian drift (see figure 27). A few of these will show the typical relationships between these two drifts where the Kansan gumbotil is present.

The following section was observed along the railroad in the northwestern part of section 28, Washington township (T. 68 N., R. 4 W.), Lee county:

		Feet
6.	Gumbotil, Illinoian, gray to ashen-colored on a dry surface; on a fresh surface, gray mottled with brown; leached; small siliceous pebbles	4½
5.	Till, Illinoian, oxidized and leached; brownish buff with some patches of gray in the upper part, fewer patches in the lower part	5½
4.	Till, Illinoian, oxidized and unleached, brownish color, breaks into irregular angular fragments	1
3.	Gumbotil, Kansan, typical dark gray or drab-colored with some patches of brown; leached; numerous siliceous pebbles	8½

2.	Till, Kansan, oxidized and leached; buff-colored with numerous patches of gray, especially in the upper part	5
1.	Till, Kansan, oxidized and unleached; many concretions; breaks into polyhedral blocks along the joint lines; exposed for	12

About a quarter of a mile south of the above described exposure, also along the railroad, there is the following section:

		Feet
4.	Loess	3
3.	Till, Illinoian, oxidized, leached	5
2.	Gumbotil, Kansan, gray	11
1.	Till, Kansan; exposed	37

The Kansan gumbotil occurs in a level band extending through the cut as is shown in figure 49. This remnant of the gumbotil plain is characteristic of the surface wherever it is found. It is uniformly level, and the gumbotil is never found in place mantling slopes.

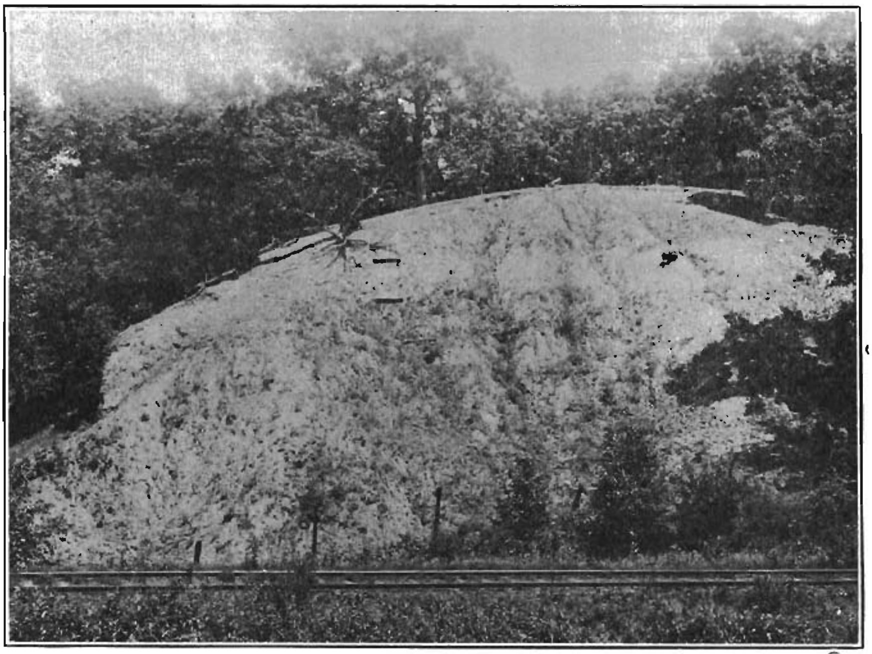

FIG. 49.—Cut in Lee county showing band of Kansan gumbotil extending through a hill. Illinoian till above the gumbotil; Kansan till below.

About one and a half miles northwest of West Point, on the north line of section 3, West Point township (T. 68 N., R. 5 W.), Lee county, a good section was found showing both the Kansan and Illinoian gumbotils in normal relationships. The section showed:

		Feet
4.	Loess, buff, about	8
3.	Gumbotil, Illinoian, typical, gray	3
2.	Till, Illinoian, oxidized but with only the upper part leached	11
1.	Gumbotil, Kansan, exposed	11

The Kansan till below the gumbotil was not exposed in this section.

A section showing the Kansan gumbotil with the full thickness of the Illinoian drift above it was seen in a road cut on the south side of a creek in section 34, New London township (T. 71 N., R. 5 W.), Henry county. The sequence of materials is as follows:

		Feet
6.	Loess, buff, leached; to the upland	8
5.	Gumbotil, Illinoian, leached, with upper part gumbotil-like but with much of the colloidal material carried out. Chocolate-colored in upper four feet, less reddish below	7
4.	Till, Illinoian, oxidized but unleached, looks very much like the Kansan till; measured along slope	40
3.	Gumbotil, Kansan, drab-colored, tough, leached but some lime concretions, few pebbles	11
2.	Till, Kansan, oxidized and leached	5½
1.	Till, Kansan, oxidized and unleached, seen down to creek bed	12

In places in Illinois[4] loess has been found separating the Kansan till from the Illinoian till but in Iowa thus far no loess has been found by the writers at this horizon.

KANSAN DRIFT UNDER IOWAN DRIFT

Within the area of the Iowan drift there are a number of exposures of the Kansan gumbotil, all overlain by Iowan till, figure 50. Four sections typical of many others will be described here.

About a hundred yards west of the middle of the line between sections 30 and 31, Massillon township (T. 82 N., R. 1 W.), Cedar county, a shallow road cut exposed about two feet of loess over a foot and a half of Iowan till. Under the till is Kansan gumbotil with a thickness of over two feet in the exposure. The elevation of the gumbotil was determined to be 795 feet. Within section 31, to the south, the Iowan drift rises in hills to an elevation forty-five feet above the Kansan gumbotil, this figure therefore representing the thickness of the Iowan drift and Peorian loess in this place.

[4] Leverett, Frank, The Illinois Glacial Lobe: U. S. Geol. Survey, Mon. 38, pp. 114-115, 1899.

Near the west end of the line between sections 30 and 31, Massillon township, the Kansan gumbotil occurs also in the road ditches. It is here a typical drab sticky material, differing much from the yellow and brown Iowan till which lies over it. The surface of the gumbotil shows some disturbance, for it is undulatory, with the crests of the ridges a few inches apart, and the

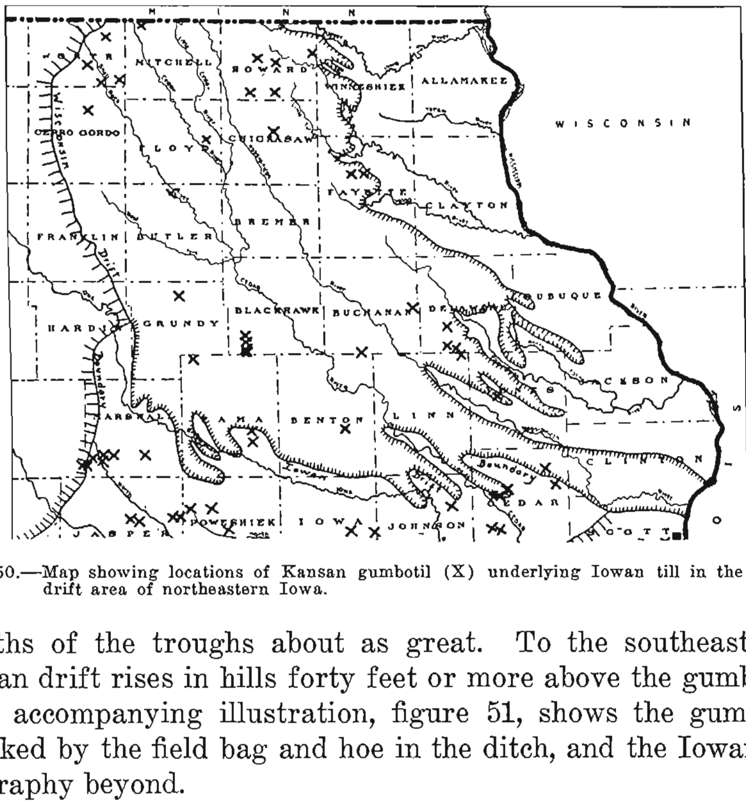

FIG. 50.—Map showing locations of Kansan gumbotil (X) underlying Iowan till in the Iowan drift area of northeastern Iowa.

depths of the troughs about as great. To the southeast the Iowan drift rises in hills forty feet or more above the gumbotil. The accompanying illustration, figure 51, shows the gumbotil marked by the field bag and hoe in the ditch, and the Iowan topography beyond.

About four miles north of Anamosa, in section 30, Wayne township (T. 85 N., R. 3 W.), Jones county, is a cut showing Kansan gumbotil with Iowan till and Peorian loess above it. The materials are exposed on both sides of the road and a composite section is as follows:

		Feet
3.	Loess, buff, sandy	2 to 4
2.	Till, Iowan, sandy with numerous pebbles, oxidized to a brownish buff color	1 to 4
1.	Gumbotil, Kansan, dark gray, leached, upper 1 foot shows some evidence of lamination and is filled with carbonaceous matter—an old soil	7

The gumbotil was exposed along the road for a distance of about 50 yards. Near the south end of the exposure the accompanying photograph, figure 52, was taken. The white line marks the position of the top of the gumbotil.

Near the middle of the north line of the northeast quarter of section 16, Windsor township (T. 94 N., R. 9 W.), Fayette county, the Iowan till is shown over gumbotil of Kansan age. The elevation of the gumbotil is 1200 feet, and the material is seen at about the same elevation in several cuts along the road to

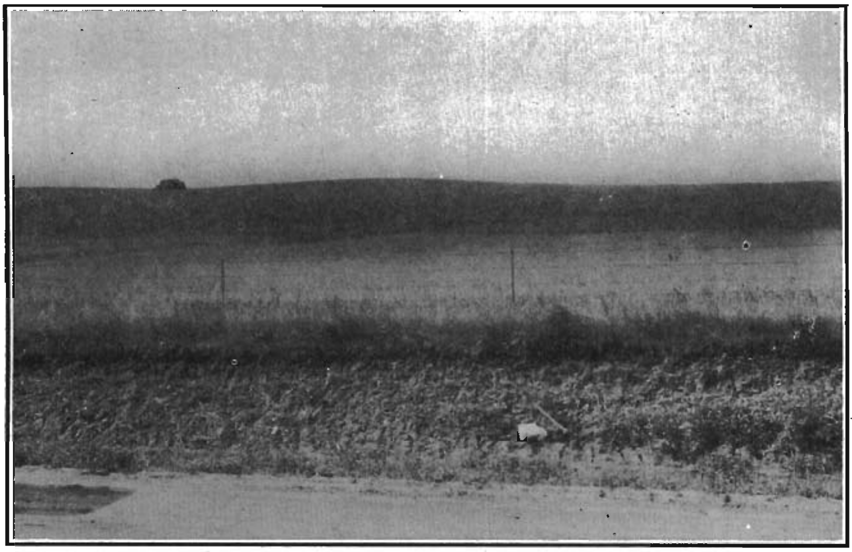

FIG. 51.—Kansan gumbotil in Cedar county (marked by bag and hoe) with Iowan topography in the background.

the east, within the few miles to West Union. The section made in the main cut is as follows:

		FEET
5.	Loess, Peorian, buff, mealy; unleached; some concretions; no fossils found	2
4.	Till, Iowan, dark buff on a dry surface, yellowish brown to brown when damp; cuts readily with the hoe; sandy; few concretions; unleached to the surface	7
3.	Loess, Loveland, gray with considerable chocolate-colored stain; leached; laminated; putty-like when wet; no pebbles found	2½
2.	Gumbotil, Kansan, dark gray on a dry surface; leached; no concretions seen; very few pebbles of any kind, and those present are siliceous; upper foot and a half has much carbonaceous matter which shows as a distinct soil band through the cut	5½
1.	Till, Kansan, oxidized and leached, grades into the gumbotil; pebbles abundant, exposed	4½

The accompanying figure 53 shows the east end of this cut and in the background the Iowan surface, which rises 37 feet above the gumbotil. The upper part of the hills is loess. The thickness of the Iowan till above the gumbotil was measured as being eighteen feet and probably exceeds twenty feet here.

In the northern tier of counties there are several localities in

FIG. 52.—Kansan gumbotil, with Iowan till above, in Jones county. The white line marks the top of the gumbotil.

which the Kansan gumbotil is known within the area of the Iowan drift of northeastern Iowa. One of the best exposures, and also the one farthest north, is in the middle of the west side of the northwest quarter of section 14, Otranto township (T. 100 N., R. 18 W.), Mitchell county. In a road cut about four feet of typical Kansan gumbotil is exposed while in a small gravel pit just east of the road there is three feet of the same material. The gravelly material which has been worked in the pit is about six feet thick and contains a variable quantity of clay, in some

FIG. 53.—Cut in Windsor township, Fayette county, showing Iowan till over loess on Kansan gumbotil.

places very much resembling till. The upper five feet of the gravelly till, which is interpreted as being Iowan in age, is leached, but the one foot just above the gumbotil contains much limestone as pebbles and cobbles, and lime in the clayey matrix effervesces strongly with acid. All of the Iowan is much oxidized and in places bands several inches thick are cemented into a conglomerate with a ferruginous cement. The elevation of the gumbotil under the Iowan till here is about 1175 feet.

KANSAN DRIFT UNDER WISCONSIN DRIFT

The Wisconsin drift covered the Kansan drift after the lapse of two glacial and three interglacial stages. The time was therefore long, and the contact of the Wisconsin and Kansan tills without intervening materials would not be expected to be common. There is one series of cuts which shows the youngest till over loess which lies on Kansan gumbotil. These cuts are along the Chicago, Milwaukee, St. Paul and Pacific railway west of Rhodes, on both sides of the Marshall-Story county line. A typical section is found about two miles west of Rhodes and is as follows:

		Feet
5.	Drift, Wisconsin, sandy; partly leached for six feet and here more reddish than below; general color yellowish, with the lower part more sandy and tending toward gray	30
4.	Loess, buff, highly fossiliferous	11
3.	Gumbotil, Kansan	8
2.	Till, Kansan, oxidized and leached, grading up into the gumbotil; thickness indeterminable because of slumping.	
1.	Till, Kansan, oxidized and unleached, slumped.	

East of the above cut, in the north part of section 19, Eden township (T. 82 N., R. 20 W.), Marshall county, a long cut was made to accommodate the track in a curve. A general section here is the same as above, but the relationships of the materials were better shown when the cut was newly made. A photograph of this cut by W. C. Alden is shown in figure 54.

A second locality showing the same relationships, except that the loess is absent and the Wisconsin till rests upon the Kansan gumbotil, is in the northwest quarter of section 4, Colfax township (T. 79 N., R. 28 W.), Dallas county.

Lees has recently found two exposures of gumbotil beneath the Wisconsin drift in the central part of the Wisconsin drift area. One of these is north of the Illinois Central railroad at the east end of the bridge across Des Moines river in section 19,

FIG. 54.—Cut southwest of Rhodes, Marshall county, showing Wisconsin till, loess, Kansan gumbotil and Kansan till. (W. C. Alden.)

Wahkonsa township (T. 89 N., R. 28 W.), Webster county. The other is at the northwest corner of section 17, Avery township (T. 92 N., R. 30 W.), Humboldt county. The precise age of these gumbotils is not known, though Lees is inclined toward the opinion that the latter one is Nebraskan in age.[5]

Descriptions of the Drift Phases

THE KANSAN GUMBOTIL

The field differences between the various phases of the Kansan drift are as constant as are those in the Nebraskan drift. As in the older drift, the gumbotil of the Kansan is the most distinctive phase of the glacial materials. The color of the Kansan gumbotil is ordinarily a light to neutral gray on the dry surface, with the color lighter where surface wash has uncovered parts of the light colored included sand grains. There are occasional dark brown and reddish brown masses which mark the concentration of iron oxide along joints or around roots as tubules. The dominant color, however, is gray, which distinguishes the gumbotil in most cases from the other till phases and from the loess. When wet the gumbotil is darker in color than when dry and it shows a series of blues and purples in delicate tones over the gray. The colors are not conspicuous, and the dark to neutral gray of the wet gumbotil is in itself enough contrast with the colors of the other till phases to make it a distinctive property.

The surface feature of color in the gumbotil is augmented as a distinction by the surface cracking which is characteristic of the gumbotils of all ages. The development of the cracks separating the surface of the gumbotil into polyhedral blocks regularly follows the wetting and drying of the gumbotil, and therefore any gumbotil which has been exposed for some time has this characteristic feature developed. The first cracking on drying of the gumbotil is along a series of intersecting, irregular, angular lines which separate the surface into blocks ranging from about an inch to two inches in diameter, with the corners sharp and the sides usually broadly curved.

Additional drying of the surface develops a series of smaller, shallow cracks which subdivide the larger blocks into smaller

5 Lees, James H., Geology of Crawford County: Iowa Geological Survey, Vol. XXXII, p. 317, 1927.

blocks a fraction of an inch across, and these give to the surface a crumbling appearance. Actually, the surface is rather firm and the small blocks, while they may be separated, are not loose on the surface. The cracks between the larger blocks range between a quarter and three-quarters of an inch deep, while the smaller cracks are usually less than half an inch deep, thus giving to the smaller blocks something near equidimensions in width and depth.

The mass texture of the Kansan gumbotil differs from that of the Nebraskan in that it is usually somewhat more evident, both when wet and when dry. This is perhaps due to the difference in compression which the two gumbotils have undergone for the Nebraskan gumbotil was overriden by heavy Kansan ice, while the Kansan gumbotil exposures are most common in areas where no later ice has transgressed. In the Kansan gumbotil, the 'starchy' fracture and crumbling character are very evident in the material which is wet enough to mould in the hand. Also when the gumbotil is dry there is enough parting through the mass to cause the typical hackly surface to appear when it is broken, though the crumbly character is not very evident in the dry specimens. The small fragments which break apart to give the crumbling appearance are usually less than a quarter of an inch in diameter, and they range through all sizes up to this limit. The shapes of the fragments have a wide range. Some of them are almost round, others are markedly polyhedral, and still others are of flakelike form with either square or tapered edges. The faces of the pieces are usually striated, or ridged in one direction, with at least some of the ridges determined by the presence of sand grains in the matrix along which the face was developed. There may be tapering cones of clay on opposite sides of the grains, making a ridge which is alined with the other ridges on the same face. The presence of these double cone ridges and the parallelism of all the ridges suggest that they are the product of movement within the gumbotil which has resulted in slippage along closely spaced surfaces. From the parallelism with the mass texture of slumped loess, it is suggested that the flaky mass texture of the gumbotil may be the product of slumping or of movement which has a considerable lateral component.

The clastic texture of the Kansan gumbotil follows very closely that of the Nebraskan in distribution of the different size grades. The clay and silt are the highest in percentage, with about three-quarters of the specimens having between sixty and seventy-five per cent of the grades below 1/64 millimeter in diameter. One of the thirty-three specimens analyzed was very sandy and showed only 35.9 per cent of the clay and silt grades. The others were distributed as follows:

	Below 1/64 millimeter in diameter					
Percentage	55-60	60-65	65-70	70-75	75-80	80-85
No. specimens	4	7	7	11	1	2

As in the Nebraskan gumbotil there are more specimens with the silt and clay content below sixty per cent than there are with the content above seventy-five per cent.

Slightly more than half of the specimens of Kansan gumbotil analyzed show the percentage of sand of the grade 1/16 to 1/32 millimeter higher than the next smaller grade, 1/32 to 1/64 millimeter. The values of the larger grade range between 6 per cent and 24.2 per cent, and those of the smaller grade, between 7 per cent and 19.0 per cent. The sand and pebbles which are coarser than 1/16 millimeter make up from less than 1 per cent to 25 per cent of different specimens, except the especially sandy gumbotil, which shows 45.3 per cent above 1/16 millimeter.

The parallelism of the three sand grades, 1/2 to 1/4, 1/4 to 1/8, and 1/8 to 1/16 millimeter, is as striking in the Kansan gumbotil as in the Nebraskan gumbotil. The following table shows the percentages determined in the different specimens:

Spec. No.	60A	74A	75A	86A	87A	133A	134A
1/2 to 1/4 mm.	0.9	0.6	0.1	1.1	1.1	2.5	3.0
1/4 to 1/8 mm.	1.1	0.8	0.1	1.6	1.4	6.6	4.9
1/8 to 1/16 mm.	1.1	0.8	0.1	1.8	1.5	9.9	5.5

138A	140A	148A	149A	150A	174A	179A	182A
3.9	5.2	8.0	3.5	2.1	1.5	3.4	1.4
4.4	5.8	7.3	2.6	1.8	1.1	5.0	1.4
4.3	6.2	6.2	3.3	1.7	1.0	6.2	1.6

188A	192A	193A	204A	208A	217A	218A	219A	224A
1.0	2.2	2.3	5.7	3.3	0.9	0.1	0.3	tr*
1.2	2.3	2.0	5.7	3.2	1.4	0.2	0.3	tr*
1.6	2.9	2.0	7.3	3.4	1.9	0.2	0.4	2.0

229A	230A	244A	246A	265A	268A	289A	304A
0.1	0.2	2.6	0.2	tr	0.2	0.1	0.4
0.1	0.2	2.3	0.3	1.0	0.6	0.1	0.4
0.2	0.6	2.3	0.4	0.3	1.4	0.2	0.6

* Less than 0.1 per cent

The size grade distribution within the gumbotil is variable. The greater sand content is always at the expense of the silt and clay so that these two vary inversely. Proportions between other grades are so different in different cases that no general statement seems justified. The correlation of the Kansan gumbotil, or the certain identification of this material on the basis of mechanical analysis alone is as uncertain as it is in the case of the Nebraskan gumbotil. The analyses and the numerical results are of more value in suggesting origin and the present condition of the material than in correlating or identifying the gumbotil.

The pebble content of the Kansan gumbotil is of the same character as is that of the Nebraskan gumbotil. The average of seven analyses from different places shows the following percentages of the various rocks:

	Per Cent
Quartz	48.5
Chert	31.8
Quartzite	6.8
Granite	7.8
Greenstone	2.9
Feldspar	1.0
Sandstone	.5
	99.3

(Analyses by Kay, Alden, and Dewey.)

These analyses approximate those secured from other places and the above average represents well the high siliceous pebble content of the gumbotil. Over eighty per cent of the pebbles in the gumbotil are siliceous, while about eight per cent are composed of granite, which has a high silica content.

The pebble content of the gumbotil of Kansan age agrees well with the interpretation that it is a residual weathered product of the till. The high content of rocks resistant to the ordinary weathering processes, the low content of those composite rocks which are composed of minerals which weather easily, and the almost complete absence of pebbles of ordinary country rocks, which in this region are sedimentary, lead to the inevitable conclusion that some efficient selective process has reduced the normal pebble content of the till. There is no source from which the materials forming the gumbotil could have been derived, transported, and deposited without having incorporated with them fresher till detritus which would noticeably alter the results of the analyses of the pebble content of the gumbotil. Weathering is the only selective process known to have been at work where the gumbotil is found, and the present pebble content of the gumbotil is such that an appeal to this process is fully adequate to account for all of the peculiarities of the gumbotil pebble content.

The roundness of some of the pebbles from the Kansan gumbotil was determined by means of the rolling device used on the Nebraskan till pebbles. With .00 as the value of an unabraded cube and 1.00 for a perfect sphere, the following figures represent the average roundness values obtained for pebbles from the Kansan gumbotil. The pebbles between 8 and 16 millimeters in diameter showed the following roundnesses:

Roundness:	.00	.03	.06	.10	.15	.19	.24	.26	.29	.33	.36	.40
Percentages	48	16	19	9	5	3						

The pebbles between 4 and 8 millimeters in diameter gave the following average roundness values:

Roundness:	.00	.01	.07	.13	.17	.23	.27	.31	.36	.40	.44	.48
Percentages	17	21	23	19	9	6	3	1	1			

The pebbles with a diameter between 2 and 4 mm. showed the following average roundnesses:

Roundness:	.00	.06	.11	.20	.26	.32	.37	.44	.48	.53	.59	.63
Percentages	17	15	23	23	11	6	3	2	*			

There were not available sufficient composite rock pebbles to make determinations for comparison with the siliceous pebbles, so they were not determined separately.

A large number of broken chert fragments in the Kansan gumbotil give to the roundness figures a high percentage in the more angular values for the largest pebbles. In this size grade there are few composite rock pebbles, and they therefore modify the roundness figures but little. Where chert pebbles remain unbroken they give roundness values comparable to those of the Nebraskan gumbotil. In the four to eight millimeter grade the very angular pebbles are distinctly in the minority, and those showing some rounding make up the greater number. The slightly rounded pebbles in this grade show the maximum percentage,

* Highest roundness value obtained for the size, but less than one-half per cent in the average.

on both sides of which percentage there is a more or less regular decrease to the limits of roundness and angularity with the greater proportionate decrease on the roundness side. The pebbles of two to four millimeters diameter have the same type of distribution of roundnesses as do those of the next larger grade, with the exception that the pebbles showing slight roundness are fewer than those which are angular. The percentage curve is apparently not quite as long and is a little steeper than in the case of the larger pebbles, but the values are higher and the intervals greater, which serves to account for much of the difference.

In none of the cases is there a well defined upper limit to the rounding, for the percentage of the different values grades downward to a point well above the bulk of the roundnesses. The most rounded pebbles are usually those of chert, while those showing moderate rounding include most of the composite rock types found in the gumbotil. Weathering toward the more rounded forms is limited apparently in the extent to which the modification of shape can be carried, for the impress of the original shape is retained to the point of disintegration in most cases.

The Kansan gumbotil is a distinctive drift material. It derives its distinction mostly from its gumbo character. Its identification is possible by means of its gray color and the polyhedral blocks which form over the surface after it has been wet. Verification of the kind of material lies in the determination of its leached character and in the presence of pebbles, but of only those pebbles most resistant to weathering, with a preponderance of those which are siliceous.

The laboratory studies of the Kansan gumbotil show it to be a material of wide differences, particularly in clastic texture and roundness of the fragments. The average values secured for the different features of the gumbotil may be only roughly approximated by the analysis of any single specimen, and two specimens may differ very widely in the numerical results derived from their laboratory study. There are, however, features of proportion between different parts of the various analyses which indicate a parallelism in nature between specimens of the gumbotil from different places. In the mechanical analyses this consists in the usual approximation of the same percentage by three sand grades, and in the order of occurrence of the percentages of the smaller clastic grades. In the roundness figures the parallelism between specimens shows in the same general proportion of the various values for the roundnesses of the different sizes. The lithology of the gumbotil is perhaps the most constant of its laboratory characters, but in this also there is wide variation so that any single specimen may fall far from the average analysis even when it is known to come from undoubted gumbotil. In the Kansan gumbotil, as well as in the Nebraskan, the feature of variety within wide limits is the one constant character, but with enough consistency present to make possible the certain identification of the material in the field and the production of corroborative testimony from the laboratory.

The Kansan gumbotil developed to greater depth than the Nebraskan gumbotil. The maximum thickness of this extremely weathered material on the Kansan drift is about 15 feet, but the average of 40 sections where the gumbotil appears to be complete is 11.2 feet. The sections chosen to represent the thickness of the gumbotil were those where the soil at the surface is still preserved beneath the covering material, or those where the gumbotil is exceptionally thick. In the former case it is not certain of course that the soil on the surface of the gumbotil was not developed after some erosion had taken place, and in the latter case it may be that some of the greater gumbotil thickness is due to secondary accumulation of the material on top of that originally formed, but in no case used was there any determinable evidence that there had been such erosion or addition.

OXIDIZED AND LEACHED KANSAN TILL

The complete average section of Kansan drift has about five and a half feet of oxidized and leached till below the gumbotil. Local variations cause this thickness to be slightly less or a little greater, but most of the exposures, and the average of all, are very close to this figure. The contact of the oxidized and leached till with the gumbotil is gradational, and the transition zone through which the change takes place may be from a few inches to more than a foot in thickness. The contact is of the same type as that between the same two zones of the Nebraskan till. There is an interfingering of the two materials, with the greatest development of the gumbotil along the joint planes which pass from the gumbotil into the till below. The till between the joint planes usually is oxidized and has the characteristic brownish buff color, while next to the joint planes and extending deeper into the subjacent till in the upper part of the transition zone are the grays of the deoxidized gumbotil phase. The feathering out of the oxidized and leached till into the gumbotil along the sides of the joints, and the interfingering of the gumbotil and oxidized and leached till masses are the typical features of the transition zone at the top of the oxidized and leached till, figure 55.

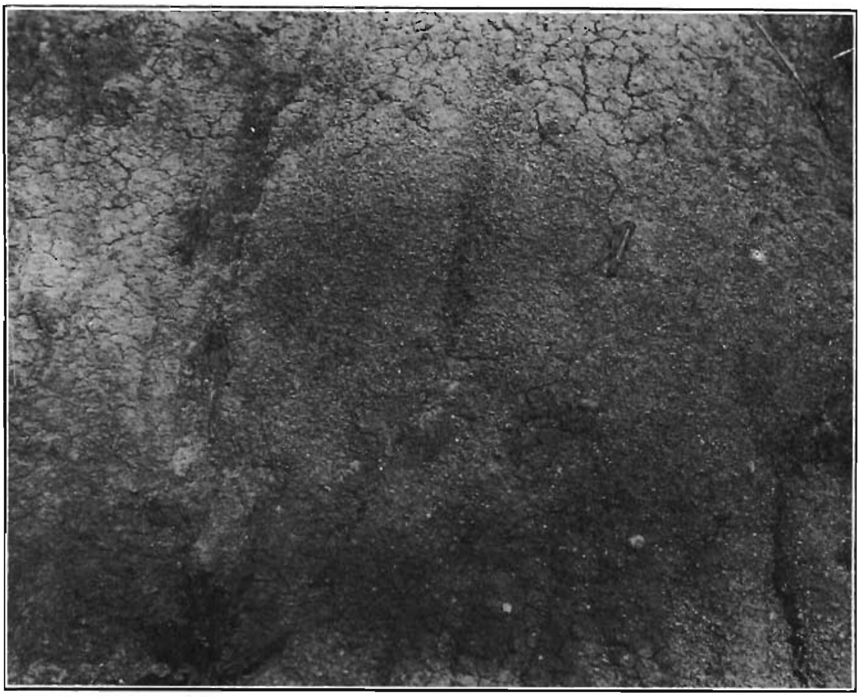

FIG. 55.—Disintegrating granite boulder in transition zone between Kansan gumbotil and Kansan oxidized and leached till; middle of northwest quarter of section 23, English township, Lucas county.

At the bottom of the oxidized and leached till phase the same type of interfingering extends into the oxidized and unleached till, with the exception that there are only very minor color differences. The parts of the mass along the joints are leached first, while the interiors of the joint-bounded blocks still retain their calcareous nature. The use of the acid bottle is the only certain way of differentiating the two phases of till on the basis of leaching. Within the zone which is mostly leached the mass of clay may have all the small calcareous material removed but still retain small pieces of chalky limestone which are remnantal from much larger limestone fragments. The surrounding material will show no effervescence with acid, but a zone of a quarter of an inch or so around the limestone, and perhaps for an inch or two below the pieces, will show a slight reaction to acid while the fragments themselves will effervesce strongly. Around the calcareous center there is ordinarily a thin clayey film, powdery when dry and slippery when wet, which is the residual material left from the leaching of the outer part of the limestone piece. Such fragments occur only near the base of the oxidized and leached zone, though they are occasionally in positions which require them to be included within the oxidized and leached zone, for they may be the only material within several inches of the typical unleached till that will effervesce.

Within the mass of oxidized and leached Kansan till the color is a reddish buff or brownish yellow, lighter on the dry surface than on the moist, and with a distinct gray cast over a surface which has been washed so as to expose a portion of the sand content. The color is in striking contrast to the color of the gumbotil though it differs but slightly from the oxidized and unleached zone below it. The surface cracking of the oxidized and leached Kansan till is very much like that of the same phase of the Nebraskan till. After being wet and dried the surface is crossed by numerous angular cracks which separate it into blocks which are comparable to those formed by wetting and drying of the gumbotil surface. These blocks are not as widely separated as those in the gumbotil, and they are crossed by other cracks which are smaller and which give to the surface a coarsely granular appearance.

The mass texture of the oxidized and leached Kansan till is distinct from that of the gumbotil. The till is separated into blocks by the presence of several series of joints, which extend through the mass at irregular intervals and in roughly parallel directions. The shapes of the blocks are thus crudely prismatic and they range from less than an inch to several inches in each dimension. The hackly fracture of the gumbotil is duplicated only in the transition zone and in the immediately subjacent till.

The small striated block structure of the gumbotil is absent in the oxidized and leached till. The joints which mark the boundaries of the till blocks are definite planes along which the till breaks, but they are not conspicuous except in the transition zone where the gumbotil phase is developed along their borders and not in the adjacent till. The oxidized and leached till as a whole is compact, very hard when dry, and only slightly pervious to water, except along the joint planes. It is in physical character seemingly only a step removed from the gumbotil phase which in the natural exposure is so closely related to it.

The clastic texture of the oxidized and leached Kansan till offers the same variety as does the clastic texture of the till everywhere. The clay and silt content, the sizes below 1/64 millimeter in diameter, was found to range between 29.9 and 59.3 per cent. These percentages differ inversely as the percentages of sizes larger than 1/64 millimeter with the difference tending to be proportionally distributed through all size grades represented.

The specimens analyzed show a greater percentage of the size grade between 1/16 and 1/32 millimeter than between 1/32 and 1/64 millimeter, and they have the three sand grades approximating the same percentage as in the gumbotil. These characteristics indicate a parallelism between the gumbotil and the oxidized and leached till, which is in harmony with the interpretation of a till genesis for the gumbotil.

The lithology of the oxidized and leached Kansan till is well shown by the analyses of collections of pebbles from widely separated places. The averages of two series of analyses are here given. Those in the first table were made by G. F. Kay, A. H. Dewey and W. V. Knoll, and those in the second table were made by R. T. Chamberlin, W. C. Alden and M. M. Leighton. All the pebbles were from the oxidized and leached Kansan till from Iowa localities.

I

	Per Cent
Quartz	16.8
Chert, flint, etc.	16.5
Quartzite	8.0
Granite	20.3
Basalt and greenstone	25.5
Feldspar	1.0
Felsite	7.0
Sandstone	1.0
Quartz porphyry	.6
Slate	.5
Schist	2.3
Gneiss	.3

II*

	Per Cent
Limestone and dolomite	3.
Shale	2.
Sandstone	3.
Quartz	7.
Chert	16.
Hematite and jasper	1.
Quartzite	15.
Quartzose	2.
Schist	1.
Porphyry	1.
Granite	17.
Syenite	2.
Greenstone	19.
Diorite	5.
Other crystallines	4.

The abundance of basalts, greenstones and granites indicates that the weathering processes have not yet reduced this till to the stage of complete disintegration for even some of the weaker composite rocks. Most of the ferromagnesian rocks, however, show alteration at the surface, and many are completely penetrated by the color changes which take place with the decomposition processes. The granites are usually fresh, hard, and as yet show little sign of alteration, though some of the feldspars show under the microscope alteration along the cleavage planes. Schists, while nowhere very abundant in the till, probably show more alteration in the oxidized and leached phase than any of the other common rocks. The lines of schistosity are planes of weakness along which the rock splits readily and weathering alterations start with mechanical disintegration, which is followed by the chemical reduction of the unstable minerals in the rock. The siliceous rocks, which make up about 40 per cent of this phase of the till, are not noticeably changed by the processes which have brought about the oxidation and leaching of the matrix in which the rocks occur.

Determinations were not made of the roundnesses of the pebbles of the oxidized and leached Kansan till as the available collections were inadequate to represent that phase of the till for comparison with the other phases.

The oxidized and leached Kansan till is distinctly a transitional phase between the oxidized and unleached till below and the gumbotil above. The gradations link it inseparably with the other two phases and indicate that it is the intermediate step in

* Iowa Geological Survey, Vol. XXVI, p. 187.

the formation of the final till product, the gumbotil, under the influence of weathering.

Erosion has removed the Kansan gumbotil in many places, leaving some other phase of the Kansan drift as the top material. The oxidized and leached till phase is present where only the gumbotil has been removed or where erosion uncovered the unleached drift sufficiently long ago and under such conditions that leaching has since taken place. In either case, the oxidized and leached till phase at the surface of the till commonly has an

FIG. 56.—Ferretto zone on Kansan till and below loess.

accumulation of oxidized iron which gives to it a more reddish color than is present in the till phases below. This distinctly reddish compact leached till at the top of the drift is called the ferretto zone, figure 56. In the areas where the ferretto zones are seen, they are developed best below the level of the gumbotil plain in approximately the topographic position of the contact zone between the gumbotil and the oxidized and leached till. On the surface of the reddish oxidized leached till there is in many places a concentration of pebbles known as a pebble band. This is present on the Kansan drift beneath the loess in many places.

OXIDIZED AND UNLEACHED KANSAN TILL

The oxidized and unleached Kansan till forms the greater part of the thickness of the Kansan till in most places. It is the common yellow boulder clay which is the typical expression of the drift below the loess over large areas of the southern and western parts of the state. The oxidized and unleached till is limited above by the transition zone through which it grades into the oxidized and leached till. This zone is formed by the leaching of the till along the joint planes while the interiors of the joint-bounded blocks still retain their unleached character. The transition zone between the leached and the unleached till is thicker than the transition zone between the unleached zone and the gumbotil, and though the line marking the upper limit of the calcareous material may usually be determined within an inch or two the leached sides of the joints extend several inches and in some places more than a foot below this line.

The base of the oxidized and unleached till is an indefinite line, for the gradation from this till into the unoxidized till is a broad zone marked by alternating masses of each kind of till. The more widely spaced joints bound masses that are several feet across, whose centers are unoxidized, but whose outsides are oxidized to a considerable degree. Complete oxidation of smaller masses between the larger and the oxidation along horizontal joints give the impression of the incorporation of unoxidized till in oxidized till. The oxidation, however, has surrounded masses of the unoxidized till, leaving it to testify to the former condition of the whole mass. This transition zone may be many feet in thickness, the oxidation being more restricted to the vicinity of the joints and the joints being less numerous as the bottom of the transition zone is approached. Toward the upper part of the zone the masses of unoxidized till are smaller and less numerous, and the joints are increased in number so that the oxidized part of the till is well broken by planes along which additional changes are taking place.

Within the upper part of the oxidized and unleached phase of the till, just below the transition zone, there is ordinarily an accumulation of the material leached out from the till above. This is concentrated along the joint planes in nodular masses or in a white or gray powdery filling of the joints between the blocks of till. The secondary calcareous material, added to that which was originally in the till, makes the zone immediately below the transition zone one of very high calcareous content. The thickness of the secondary calcareous zone may be only a foot or less, though usually the secondary lime is found throughout several feet of till thickness and may fill the joints for distances of a dozen feet or more below the oxidized and leached till. The concentration is usually greatest near the top of the enriched zone, just below the base of the transition zone from the leached till.

The color of the oxidized and unleached Kansan till is ordinarily a buff or brownish yellow, though here and there a brighter red or yellow color may be present. The wet and dry colors differ only slightly, the wet colors being the darker but of about the same tones as the dry. The zone of secondary calcareous enrichment is in many cases much lighter in color than the body of the till because of the white powdery lime which fills the joints and crumbles upon weathering so that it mixes with the till to alter the color of the mass. Near and within the transition zone into the unoxidized till the color is slightly more gray and somewhat darker than in the fully oxidized material throughout the bulk of the phase. The color difference between the oxidized and unleached phase of the till and the two phases above is in the case of the gumbotil very marked, but in the case of the oxidized and leached till it is only a small relative difference. The oxidized and leached till immediately above the unleached till is slightly darker, and has more of the deep reds and browns represented in the color shades. The gumbotil, with its neutral gray color and mottling of dark brown and delicate blues and purples is so unlike the buff oxidized and unleached till that color is hardly a basis for comparison between them, but rather a point of contrast.

The surface of the oxidized and unleached Kansan till is subject to the same general type of weathering modification as is the oxidized and leached till. The first development under alternating wet and dry conditions is a series of intersecting cracks, dividing the surface into polygonal figures several inches across. Further drying develops new and smaller cracks within the larger figures, dividing the surface into irregular blocks of small size, some of which upon extreme drying curl slightly, giving to the surface a rough appearance. The differences between the weathered surfaces of the oxidized and leached and the oxidized and unleached till are slight. The chief difference between the surfaces of the dried till and the dried gumbotil surface seems to be in the unity and cohesion within the block unit and the size of the unit. The first surface cracks on the till separate blocks which are larger than those over the gumbotil surface. The smaller divisions of the till surface produce blocks which are of greater diameter, but thinner, and more easily crumbled than are those of the gumbotil after it has been well wet and then dried.

The mass texture of the oxidized and unleached till is more variable than the texture of the till phases which have been described. Near the top the continuations of the joints which separate the leached till into prismatic blocks make a like separation within the unleached till. It is along these joint planes that the concentration of the secondary calcareous matter is greatest. A large number of the well developed joints do not extend to a great depth but are replaced by a series of major and minor joints which separate the till into about the same sized blocks, but which apparently do not furnish the same facility for the seepage of water as do the upper joints. This is noted in localities where the zone of secondary calcium carbonate is thick. In the upper part of the zone nearly every joint plane carries its quota of lime, but as the deeper parts of the zone are attained the planes along which the carbonate is deposited are fewer, though the deposit is present in only slightly less abundance, apparently, than higher up. The smaller joint planes are found upon digging into the till and cracking it apart.

In the lower part of the oxidized and unleached till there are evident only widely spaced joints with a very imperfect set of secondary joints separating the masses several feet in diameter into smaller blocks a few inches across. Under the strain of blows or pressure the material breaks with a slightly conchoidal fracture. Separate blocks are with difficulty quarried out of the lower part of the unleached and oxidized till, though they may be easily obtained with joint boundaries near the upper part of this phase. The perfection of the larger system of joints is well shown by the pattern of oxidation within the transition zone into the unoxidized till. Masses several feet in diameter are bounded by joints which are favorable courses for the agents which perform the oxidation. For distances of several inches on either side of the joint plane the till may be oxidized, but the interiors of most of the masses are so compact that there is no sign of till alteration beyond the vicinity of the widely spaced joints.

The clastic texture of the oxidized and unleached Kansan till is typical of that of unsorted glacial débris derived from surfaces long subjected to weathering. A clay and silt matrix makes about half the mass and more than half the bulk of the till. In this matrix are embedded the rock fragments of the sizes up to the maximum found in the till. Between one-third and two-thirds of the mass of the pieces larger than silt is in the size grades of sand, and the rest of the mass is distributed through the larger sizes. Each of the three sand grades, 1/2 to 1/4, 1/4 to 1/8, and 1/8 to 1/16 millimeter, has approximately the same percentage, and the grade between 1/16 and 1/32 millimeter is uniformly greater than the next smaller grade. The proportion of the different size particles in the till and the arrangement of those particles in promiscuous fashion make of the oxidized and unleached till the ideal material for the development of the oxidized and leached phase, and then of the gumbotil, through continued weathering.

Pebble counts from the oxidized and unleached Kansan till to determine the lithology of the till show very well the unweathered nature of the material. The average of 21 analyses made by R. T. Chamberlin, W. C. Alden and M. M. Leighton is here given as typical of the till content.

	Per Cent
Limestone and dolomite	34
Sandstone	2
Quartz	2
Chert	9
Clay ironstone	2
Quartzite	5
Quartzose	1
Schist	1
Porphyry	1
Granite	14
Greenstone	27
Gabbro-diorite	2
Other crystallines	2

The abundance of limestone, dolomite, and greenstone in the till shows that the chemical changes which have taken place have been slight. Many of the limestone and fine-grained composite rocks retain the striæ made upon them when they were a part of the ice load. The greenstones are found in all stages of weathering, and there are some whose freshly broken surfaces as found in the till show the colors of the unweathered rock. The conclusion is that within the oxidized and unleached zone weathering is a slow process and that the till as found in this zone is only slightly modified from its original condition. Because of the scarcity of exposures of the unoxidized till and the apparently little altered character of the unleached till, the latter till is here described as characteristic of the glacial material from which the weathered phases were derived.

The roundness of the pebbles in the oxidized and unleached Kansan till undoubtedly is very nearly the same now as when the till was deposited. The presence of striæ on the pebbles and the freshness of many of the more easily weathered rocks indicate that there has been little modification of the fragment surfaces since they were deposited in the till. The average of the roundness determinations of several groups of pebbles from the unleached Kansan till is as follows for the 16 to 8 millimeters size grade:

Roundness	.00	.03	.06	.10	.15	.19	.24	.26	.29	.33	.36	.40	.43	.46
Percentage	50	11	11	10	7	5	3	1	1	1				*

The roundnesses of the pebbles between 8 and 4 millimeters was averaged to obtain the following figures:

Roundness	.00	.01	.07	.13	.17	.23	.27	.31	.36	.40	.44	.48
Percentage	23	20	18	15	8	5	7	3	1			*

The pebbles of the unleached till show a rather high degree of rounding compared with that shown in the till zones above. This is due in part to the presence of limestone fragments which are comparatively soft and which were therefore abraded rather readily in the small amount of working over that the drift material received by the ice. Another source of the more rounded material is the weathered and transported material which the ice found already rounded before it was incorporated in the glacier. This material is often weathered so that by the time the more altered phases of the till are developed the rounded pebbles are nearly all gone. The percentage of angular pebbles in

* Highest roundness values obtained for the size, but less than one-half of one per cent in the average.

the 16 to 8 millimeter size is not very different in the unleached material than it is in the gumbotil, but the source of the angular material is different. Besides the angular cherts which go to form the angular pieces in the gumbotil, there are angular limestone and igneous rock pebbles, which are absent from the gumbotil. The comparative figures on the roundnesses of the pebbles in the gumbotil and in the unleached till suggest that the rounding of the pebbles by weathering does not equal the roundness attained by abrasion, for the roundness of the pebbles from the unleached till is largely if not almost entirely attained by abrasion before the material was acquired by the ice. The pebbles from this till have greater rounding though the percentage of the rounded pebbles is slightly less than in those found in the gumbotil.

UNOXIDIZED AND UNLEACHED KANSAN TILL

The oxidized and unleached till differs chiefly in oxidation from the unoxidized and unleached till, except in its upper part where the concentration of the calcareous matter from above has changed the lime content. The descriptions therefore of the textures, lithologic content, and roundness of the fragments will serve generally for both the oxidized and the unoxidized unleached tills.

The difference in oxidation results chiefly in color differences which are fairly constant. The oxidized till is buff-colored throughout. The unoxidized till is a bluish or greenish gray, sometimes with a light brown tone, with the same colors evident on both the wet and dry surfaces, though the dry colors are uniformly the lighter in shade. The darker colors of the unoxidized till are in some cases due to the content of local shale in the till, while in other cases the color seems to be the direct product of the aggregation of a great variety of rocks. Whether the darker gray color of the unoxidized till is due to the deoxidation of the till materials through changes while in the ice environment, or whether the aggregation of the given varieties of rocks and minerals in comminuted form will produce the colors found, is not known. The mineral content of the till differs from place to place, but the color of the unoxidized material is too nearly constant, seemingly, to permit the color to be referred to the specific mineral content of the till.

The oxidized and the unoxidized tills grade into each other as has been stated, showing conclusively that the one is a derivative of the other, and that color difference alone is not an adequate basis for separation of two tills. Figure 57 shows the penetration of oxidation into unoxidized till along joint surfaces, with the development of a secondary set of joints roughly parallel with those along which alteration has occurred. A minor accumula-

FIG. 57.—Penetration of oxidation along joint planes into unoxidized Kansan till.

tion of secondary calcium carbonate in the unoxidized till is present in this place, which is along Lost creek, in Lee county.

The rate of oxidation of the till is apparently rather rapid. Where erosion has removed the gumbotil surface, the till is commonly found to be oxidized throughout its thickness, for the usual till over the Nebraskan gumbotil is the oxidized Kansan till. The unoxidized till is found chiefly in those localities where the section is exposed by rapid lateral erosion, or where a high steep face is otherwise exposed under a considerable thickness of till.

Thickness of the Kansan Drift

Had the surface of the Nebraskan gumbotil plain been unbroken at the time of the Kansan glaciation it would be easy to determine the thickness of the Kansan drift sheet, for a level surface of dense material like the Nebraskan gumbotil probably would have been, when frozen, but little eroded. As it was, a relief on the Nebraskan surface was developed, necessitating the filling of valleys as well as topping the divides in order to bring the new drift surface to the plain level on which the Kansan gumbotil could be formed.

The amount of relief cut in the Nebraskan drift plain during Aftonian time is not known. However, it was in some areas a marked relief as attested by the dissection which left but little of the Nebraskan gumbotil and which cut into the bed rock to considerable depths in the northeastern part of the state. Certainly the whole surface of Iowa did not have the same amount of stream cutting in all parts at the beginning of Kansan glaciation, and therefore any attempt to give an average figure would be misleading. Some post-Nebraskan relief in areas now covered by Kansan drift probably was as great at least as 400 feet. The relief in a considerable part of the area of the two tiers of counties bordering Mississippi river was much less. Farther west the dissection was still less as is indicated by the relatively large areas of Nebraskan gumbotil still persisting in the western part of the state, figure 26.

The Kansan ice overrode the erosion-modified Nebraskan drift surface and left, when it melted, a drift mantle filling the valleys and smoothing the surface to form an extensive plain almost as broad as the state itself. On this plain the Kansan gumbotil developed, and this today represents the top of the Kansan drift plain very much as it was at the time of the retreat of the Kansan ice sheet.

The material forming the Kansan drift was derived from the surface over which the ice advanced, and as that surface was in large part covered with Nebraskan drift, some of that drift was picked up and incorporated with the materials of earlier and later acquisition by the ice mass. In the field there are to be noted some evidences of the erosion of the unconsolidated surface materials by the Kansan ice. In section 5, Cherokee township (T. 92 N., R. 40 W.), Cherokee county, there were seen masses of the Nebraskan drift, somewhat altered and therefore lighter in color, in a matrix of unoxidized Kansan drift. It is in this area that the Kansan drift and Nebraskan drift differ lithologically because of the inclusion of a relatively large amount of the underlying shale in the Nebraskan drift and a much lesser amount in the Kansan.

The following relationships were observed near the middle of the north boundary of section 5, Mason township (T. 68 N., R. 35 W.), Taylor county:

		Feet
4.	Drift, Kansan, oxidized and unleached, with many concretions. The lower part of this drift has many inclusions of Nebraskan gumbotil. To top of slope	15
3.	Gumbotil, Nebraskan, characteristic of this material, and obviously the source of the material in the inclusions above	8
2.	Drift, Nebraskan, oxidized and leached	3
1.	Drift, Nebraskan, oxidized and unleached, with many concretions	22

Inclusions of sorted materials, especially in the basal part of the drift, and identifiable older drift in the Kansan indicate that the collecting of débris went on from the drift surface. The levelling action which took place—for the erosion was without much doubt greatest on the uplands—left less relief for the Kansan ice to smooth over with drift deposits, and gave to the ice some material with which to fill the valleys. Where the gumbotil surface was left on the Nebraskan drift, and where the Kansan gumbotil has been found within the same area the difference in elevation between the gumbotils is a mark of the amount of material deposited above that necessary to fill the valleys level with the hilltops.

There are more than a score of places in Iowa where the two gumbotils, the Nebraskan and Kansan, are sufficiently well known and close enough together to warrant estimates being made of the thickness of the Kansan drift between them. The thickness of Kansan drift so determined in different parts of the state is as follows:

Thickness of Drift Feet	Number of Localities	Place (County)
20	1	Johnson
23	1	Wayne
30	1	Wayne
35	1	Crawford
40	2	Crawford Delaware
50	4	Audubon Cass Adams Monroe
55	2	Lucas Shelby
60	1	Tama
65	3	Crawford Ringgold Lucas
70	2	Madison Union
80	1	Montgomery
100	1	Taylor
110	1	Lee
120-160	1	Crawford

It is thus seen that in some places the thickness of the Kansan was as great as and perhaps greater than the thickness of the Nebraskan drift. The average of the thickness figures given above is slightly over sixty feet, but this does not represent the actual average of the drift thickness because of the relatively small number of observations and the fact that they are distributed so that the smaller thickness figures represent much larger areas than do the larger figures. The average thickness of the Kansan drift above the elevation of the Nebraskan gumbotil is probably less than fifty feet, and perhaps less than forty feet. When to this figure is added the amount of drift necessary to fill the valleys cut in the Nebraskan drift surface, the Kansan drift is seen to be a massive drift, to be ranked with the Nebraskan as one of the great drifts of the Pleistocene.

CHAPTER VII

THE YARMOUTH INTERGLACIAL STAGE

The Yarmouth interglacial stage is intermediate between the Kansan and Illinoian glacial stages. The name Yarmouth was introduced by Leverett in 1898[1] and was applied first to the soil and weathered zone at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and Quincy, Illinois. Leverett stated:

''The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason, and because the name of this village is less likely to be confusing than names which are common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth not only a soil horizon but apparently a pronounced erosion between the Illinoian and Kansan sheets.''

The Yarmouth Record

The Yarmouth record then is to be found in deposits which lie between the Kansan and Illinoian drifts and in the features which were impressed on the Kansan drift during Yarmouth interglacial time. Where the Kansan and Illinoian drifts are

[1] Leverett, Frank, The Weathered Zone (Yarmouth), between the Illinoian and Kansan Till Sheets: Jour. Geol., Vol. VI, pp. 238-243, 1898; Iowa Acad. Sci. Proc., Vol. V, pp. 81-86, 1898.

present the representative features of the Yarmouth may be dated with certainty. But only a limited area in Iowa is covered with Illinoian drift and no certain equivalent of that drift is recognized elsewhere in the state. It is necessary therefore to determine by inference the age of some Yarmouth representatives where the Kansan is the youngest drift present, and to leave less specifically referred certain other features which may be at least in part of Yarmouth age. The discussion of each type of interglacial feature will be in two parts, first, where the feature is related to the Illinoian drift and therefore of known Yarmouth age, and second, where the Yarmouth age of the feature may be inferred or suggested though perhaps not demonstrated.

The Yarmouth record is preserved in the alteration of glacial materials, in the erosion of the Kansan surface, and in the deposits laid down and altered during Yarmouth interglacial time. The alteration of glacial materials during Yarmouth time is shown in the formation of the gumbotil on the Kansan till, and in the oxidation and leaching of the till below the gumbotil. It is shown also by the extreme leaching and alteration of gravels which were at the surface of the Kansan drift during Yarmouth time. Where the Yarmouth loess and silts are leached, this change took place during this interglacial epoch also if those materials are now covered by the Illinoian till. The amount of interglacial erosion is indicated with reference to the Kansan gumbotil surface. During Yarmouth time there were deposited by the wind and by streams, loess, sands, and silts. Also soils were developed and vegetal material accumulated. Within the area of the Illinoian drift these features are all definitely determinable as of pre-Illinoian age, but outside the margin of this drift, similar deposits may have been formed earlier, during the same time or at a later time.

The Buchanan Interval

The Kansan drift is the uppermost glacial material over approximately half of the state. Elsewhere this drift is covered with Illinoian, Iowan or Wisconsin drift. In the area of the Iowan drift Calvin[2] found between the Iowan drift and the under-

2 Calvin, Samuel, The Buchanan Gravels: An interglacial deposit in Buchanan county, Iowa: Amer. Geol., Vol. XVII, pp. 76-78, 1896. Also, Proc. Iowa Acad. Sci., Vol. III, pp. 58-60, 1896.

lying Kansan drift materials to which he gave the name Buchanan. As a time term Buchanan has come to be used for the interval between the Kansan and Iowan glacial stages, including the Yarmouth interglacial stage, the Illinoian glacial stage, and the Sangamon interglacial stage. The following table shows the span of Pleistocene time represented by the Buchanan interval:

GLACIAL STAGES	INTERGLACIAL STAGES	
Wisconsin		
	Peorian	
Iowan		
Illinoian	Sangamon	Buchanan interval
	Yarmouth	
Kansan		
	Aftonian	
Nebraskan		

It is necessary, if all the Yarmouth features are to be discussed, to include the discussion of some materials which are between Kansan drift and Iowan drift—that is, materials of Buchanan age—whose more precise relationships have not yet been determined.

Descriptions of Yarmouth Features

WEATHERED TILL: THE KANSAN GUMBOTIL

The method of formation of the most weathered phase of the till, the gumbotil, has already been stated and the weathered product has been described. The surface of the Kansan drift had during a great length of time a topographic position and such other conditions as were favorable to the development of a gumbotil more than eleven feet in thickness. Not only was the gumbotil formed but a much greater thickness of oxidation and a somewhat greater thickness of leaching was accomplished in the same time and by the same agents which produced the gumbotil.

Kansan gumbotil beneath the Illinoian drift.—The weathering alterations in the Kansan till where it was covered by the Illinoian drift are very nearly as great as in the areas where the Kansan has not been so covered. In three cuts from Lee and Henry counties described on pages 226 to 228 the Kansan gumbotil below Illinoian drift was shown to be at least eleven feet thick in each place. These cuts are in section 28, Washington township (T. 68 N., R. 4 W.), in section 3, West Point township (T. 68 N., R. 5 W.), Lee county, and in section 34, New London township (T. 71 N., R. 5 W.), Henry county. On the gumbotil in none of these exposures is there a soil to testify that the full original thickness is present. A well exposed section showing the gumbotil to be eleven feet thick with soil above it is found in section 36, Fulton township (T. 78 N., R. 1 E.), Muscatine county. This exposure will be described in detail later.

Kansan gumbotil outside the Illinoian area.—The gumbotil representing the Yarmouth stage shows about the same thickness under the Illinoian drift as elsewhere. Therefore most if not all of the Kansan gumbotil was formed during the Yarmouth interglacial interval, and wherever Kansan gumbotil is found it may be considered to represent the Yarmouth interglacial stage.

The conditions under which gumbotil could form were limited, requiring principally that there be a relatively level surface and poor drainage. Such a surface would be a plain, the surface and extension of which would be now marked by the outcrops of gumbotil found in the state. By using these to reconstruct the topography of the surface during the Yarmouth it is found that the local reliefs were slight and that in general the plain coincides with the upland levels in southern Iowa. In the area of the Iowan and Illinoian drifts it approximates the average elevation of the present surface, while beneath the Wisconsin drift it lies below the present surface. In northwestern Iowa the Kansan gumbotil is thought to have been eroded away before the Iowan glaciation, and therefore the Yarmouth plain would have been as high as or higher than the present upland levels in this region. Figure 58 is a generalized topographic map of the Kansan gumbotil plain.

WEATHERED SANDS AND GRAVELS

Theoretically, if sorted materials such as sand and gravel occupied the position of the gumbotil—that is, were at the surface of the Kansan drift—during Yarmouth time, they should show alterations comparable to the alterations which were made in till to make gumbotil. Exposures of gravels and sands which

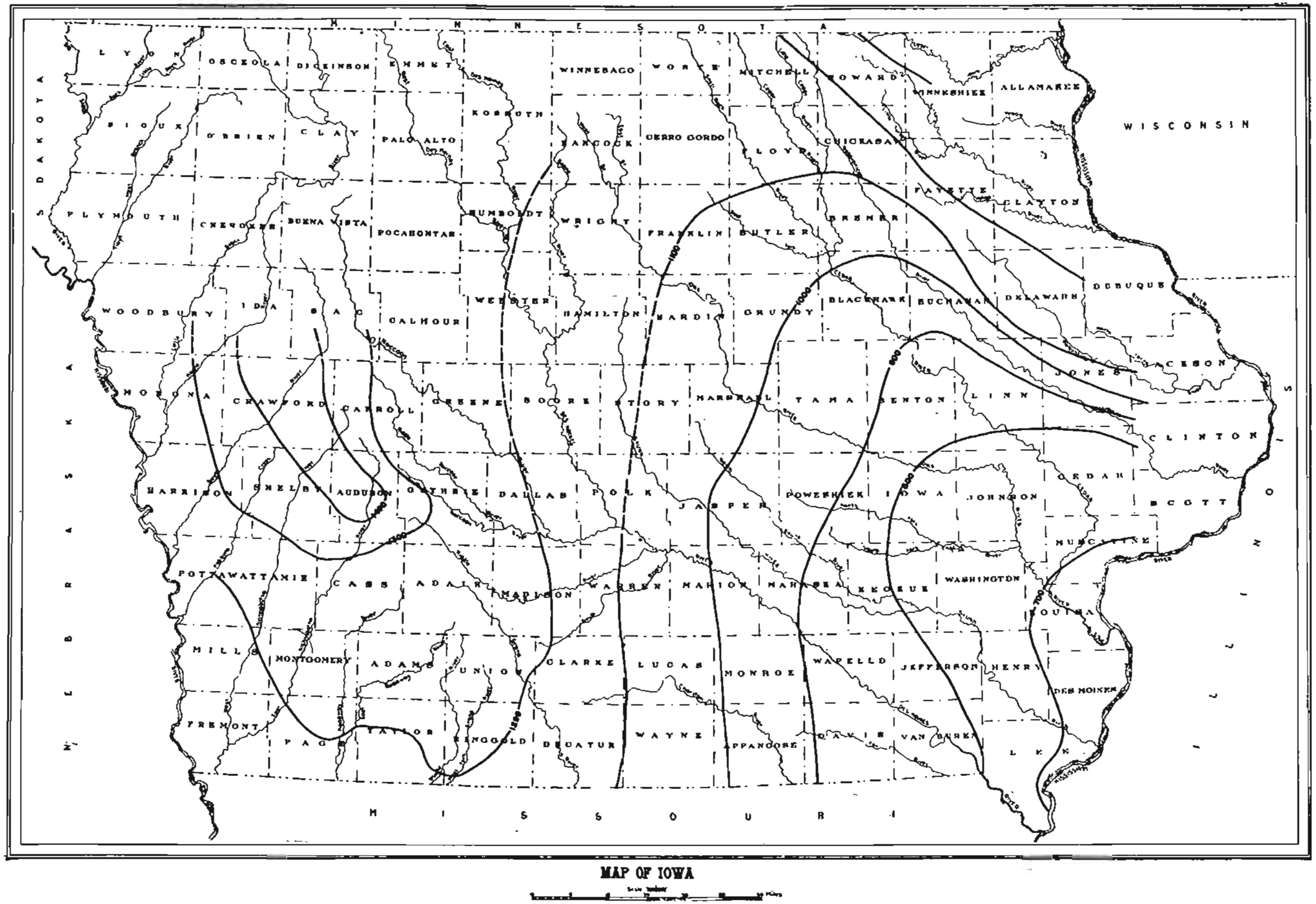

FIG. 58.—Contour map showing the surface of the Kansan plain on which gumbotil was formed during Yarmouth time. Contour interval, 100 feet.

record weathering changes equivalent to those in the gumbotil have been found in a number of places.

Weathered gravels beneath the Illinoian drift.—Only one exposure of Kansan gravels showing extreme alteration during Yarmouth time and now covered by Illinoian drift is known. This is along the side of a gully in section 20, Denmark township (T. 69 N., R. 4 W.), Lee county. The section has been described in detail on page 148 in this report. It shows twenty-two feet of thoroughly leached material consisting mostly of sands and gravels which are strongly cemented by iron oxide. The horizon is the equivalent of the Kansan gumbotil elsewhere and occurs at the elevation of the Kansan gumbotil plain in the area.

Weathered gravels outside the Illinoian area.—Weathered gravels at the Kansan drift surface are known in many places in the state, but particularly within the Iowan drift area of northeastern Iowa, where they were named Buchanan gravels by Calvin.[3] He recognized an upland phase and a valley phase of Buchanan gravels and interpreted both phases to be fluvioglacial deposits related in age to the Kansan glacial stage. He stated that the gravels of the upland phase are relatively coarse and that the materials of the valley phase consist chiefly of sand and fine gravels. He expressed the view that the upland Buchanan gravels were deposited from streams flowing on the higher areas which had become bare while yet bodies of ice filled the valleys and lowlands. Then after the ice melted from the valleys the valley Buchanan gravels were laid down. Extensive field studies in recent years have shown clearly that the upland Buchanan gravels are in knolls closely related to the Kansan till as was stated on page 138 by Alden and Leighton in Vol. XXVI of the reports of the Iowa Geological Survey. Their statement is as follows:

"At many places in the Iowan area, and especially in Buchanan county near Independence, there are low rounded knolls on the upland which apparently belong to an older deposit. These knolls contain highly oxidized and decayed ferruginous gravels, with an abundance of ironstone concretions and disintegrated granites, greenstones, and

[3] Calvin, Samuel, The Buchanan Gravels: an Interglacial Deposit in Buchanan County, Iowa: American Geologist, Vol. XVII, pp. 76-78, 1896; also Proc. Iowa Acad. Sci., Vol. III, pp. 58-60, 1896; also Geology of Buchanan County: Iowa Geol. Survey, Vol. VIII, pp. 241-244, 1898; also Geology of Howard County: Iowa Geol. Survey, Vol. XIII, pp. 67-68, 1902.

other igneous rocks. The surfaces of some of the quartzites even show etching. Calcareous material is generally lacking, having been removed by solution. Everywhere the gravels have a distinct brown color, and in all respects show great age. The materials range in size from sand to small bowlders a foot in diameter. The smaller pebbles, and many of the larger ones, can readily be cut in two by a chisel-edged hammer. These gravels are better for road-metal than those of the Iowan or Wisconsin terraces, as their more advanced state of decay permits them to pack well. Professor Calvin called these deposits Buchanan gravels and considered them as having been deposited as the Kansan ice sheet was melting away. Since they occur as knolls on the upland, it appears that they are of the nature of kames. Some of the knolls are thinly mantled with younger drift (Iowan)."

These upland deeply leached gravels are not difficult to distinguish from knolls of relatively fresh gravels of Iowan age on the uplands of the same area. Calvin's valley Buchanan gravels are now interpreted to be of Iowan age. They occupy valleys which were eroded in the Kansan drift and have close relationships to the Iowan till.

The deeply weathered upland gravels of Kansan age have the same topographic position as the Kansan gumbotil. During the time that the Kansan gumbotil was being developed by chemical weathering from Kansan till the Kansan gravels were being changed from fresh gravels to their present profoundly altered condition. Weathered Nebraskan gravels with similar relations to Nebraskan till were described on pages 186 to 191.

The weathered Kansan gravels are well exposed in several pits which have been opened in recent years in connection with the graveling of roads. One of the largest of these pits is in the southeast quarter of section 21, Burr Oak township (T. 98 N., R. 16 W.), Mitchell county, about three miles east of Osage. Here at the summit of a knoll, at an elevation of about 1170 feet above sea level, in a region of gently rolling Iowan drift topography, is a pit about 75 yards square with a maximum depth of 31 feet (figure 59). The sands are abundant and the gravels are predominantly of pebbles of small sizes, subangular in shape. Only a few boulders exceed one foot in diameter. Much of the material in the pit would pass through an 8 millimeter screen. The sands and gravels are distinctly cross-bedded and a striking feature is the color of the gravels and their depth of leaching. They are oxidized to a deep brown color, are leached throughout the exposed thickness of 31 feet, and in places they are cemented firmly by iron oxide. Overlying the gravels is thin Iowan till.

Another interesting gravel pit in Mitchell county in which Kansan upland gravels are exposed is along the county road north of Stacyville, in the northeast quarter of section 18, Stacyville township (T. 100 N., R. 16 W.). The elevation of

FIG. 59.—Kansan upland gravels in pit about three miles east of Osage.

the pit is about 1230 feet above sea level. The sands and gravels are exposed to a depth of 15 feet and are all leached. The materials consist of subangular gravels and sands in which are some boulders more than one foot in diameter. The materials are dark brown in color and are well stratified. The gravels and sands here are associated closely with Kansan gumbotil and underlying Kansan till. The gravels are at the level of the Kansan gumbotil plain, which is mantled by thin Iowan till.

In Minnesota a short distance north of the Iowa boundary is a large pit with Kansan upland gravels. It is in Mower township, six miles west and 1½ miles south of the town of Adams. The pit is cut into the level surface of the upland plain which extends southward into Iowa, where it constitutes one phase of the Iowan drift topography. Near the southeast corner of this pit there was in 1927 about six feet of calcareous sands, gravels and till interlayered with leached materials of like kind, the whole constituting the representative in this area of the Iowan till which overlay a portion of the gravels excavated. Under the calcareous material there were measured twenty-two feet of leached sands and gravels to the bottom of the pit. The material is bedded, with the dip of the beds toward the south. Slight cementation and compaction permit the walls of the pit to stand nearly vertically where they have been cut by gullying. The largest material observed in the pit did not exceed cobble size, the maximum being about five inches in diameter. The limestones are entirely absent and many of the composite rock pebbles show advanced stages of disintegration. The whole thickness of material in this pit shows oxidation, but some sand zones show less than others while some zones are very much changed in appearance by the brown iron oxides. Granite and chert are common in the gravels, as are greenstones and felsites. A count of 161 pebbles gave the following percentage distribution among the several kinds of rocks named:

Kind	Per Cent
Granite	32
Chert	26
Felsite	13
Basalt and greenstone	13
Clay ironstone	6
Quartz	3
Dolerite	2
Feldspar	1.3
Gneiss	1.3
Sandstone	.6
Quartzite	.6
	98.8

Many of the granites and most of the greenstones were much altered, many to such an extent that they could be broken with the fingers. The clay ironstone percentage may be too high as the pieces were fragments of larger concretionary masses, but in collecting and counting it could not be determined that any of the fragments came from the same larger original piece. Most of the pebbles are well rounded, with even the harder rock showing much abrasion. No striæ were found, though search was made for them.

SOIL AND VEGETAL MATERIAL

The formation of the gumbotil, and the extensive leaching of the Kansan till were in part due to the presence in the descending waters of organic compounds produced by the decay of vegetal material. The soil in which the vegetation grew and even some of the vegetation itself or carbonaceous matter from its partial decay is in places preserved at the surface of the gumbotil.

Soil under the Illinoian drift.—One of the best exposures of the soil buried under the Illinoian drift was seen at a road corner in a cut near the middle of the east half of section 36, Fulton township (T. 78 N., R. 1 E.), Muscatine county. The following section is from this place:

	Feet	Inches
5. Loess, mostly with carbonaceous matter included to make the common buff color somewhat more gray than the usual shade	1	6
4. Till, Illinoian, oxidized and leached; grades down into the unleached till, which has a thickness of about two feet. The total thickness of the Illinoian till here is about	7	
3. Soil zone on Kansan gumbotil. Dark gray to black material, upper part filled with humus and very friable. The soil zone is not everywhere present in this cut for there is evidence of plowing by the Illinoian ice, which has removed the soil in places and also a portion of the upper part of the gumbotil which is immediately below. Thickness of the humus filled soil, about		4 to 6
2. Gumbotil, Kansan, gray to drab-colored dense clay. It is leached, but the lower part contains some concretions. There are siliceous pebbles in the gumbotil, but few of other kinds	11	
1. Till, Kansan, oxidized and leached. The exposure is not sufficiently deep to bring the unleached till into view.		

In the days before the churn drill, when wells were bored or dug, diggers often noted during well excavating a horizon which contained vegetal material and soil. This zone was interpreted by Leverett[4] to be the interglacial horizon. Of this evidence of interglacial time he says:

"The accumulation of beds of peat at the surface of the Kansan drift prior to the Illinoian ice invasion constitutes as impressive an evidence of a prolonged interval as the leached and reddened surface. In the Yarmouth section the peat has a depth of 15 feet while underlying beds of sandy clay, and sand carrying bits of wood, probably also to be classified as interglacial, extend the depth of the Yarmouth

[4] Leverett, Frank, The Illinois Glacial Lobe: Mono. 38, U. S. G. S., p. 120, 1899.

deposits to 43 feet. Buried soil of black color and beds of peat have attracted the attention of well diggers in nearly every township of the region of overlap in southeastern Iowa, and specimens of the peat obtained from wells are preserved at many of the farm houses.''

Buried soil on the Kansan gumbotil outside the Illinoian area. —The presence of a soil on the Kansan gumbotil, buried under later deposits of sand, loess, or Iowan drift, is not unusual. Such occurrences have been found in most parts of the state. Whether the soil which is now found on the Kansan gumbotil is entirely Yarmouth or not is impossible to say if it is not overlain by Illinoian drift. The probability is that in part at least it is of that age, and that practically all of such soils were formed during the Buchanan interval.

The Iowan till overlies at numerous places an old soil or a carbonaceous zone at the top of the gumbotil. Alden and Leighton[5] describe it as of fairly common occurrence. The carbonaceous matter is ordinarily mixed with the upper part of the gumbotil so as to alter it somewhat in physical character and color. The plant material makes the commonly heavy gumbotil more open or porous, and therefore less dense, and is sometimes present in sufficient quantity to form a loamy soil. The admixture of carbon darkens the color to such an extent that where the humus material is abundant a black band marks the top of the gumbotil.

In some places the Peorian loess immediately overlies a soil on the Kansan gumbotil. Such a place was found between sections 6 and 7, Bear Grove township (T. 79 N., R. 33 W.), Guthrie county. The section showed:

		Feet
3.	Loess, Peorian, buff color, with lower few inches gray and containing a few dark carbonaceous streaks, to the upland	15
2.	Soil band, very dark gray, almost black. Distinct in color from the gumbotil	1¼
1.	Gumbotil, Kansan, gray, very characteristic of this material, siliceous pebbles up to ½ inch in diameter present; exposed for	4

A shallow road cut on the upland between sections 15 and 16, Prairie township (T. 68 N., R. 12 W.), Davis county, showed a foot of dense dark gray soil on gumbotil. The admixture of plant matter was apparently not sufficient to change the physical

5 Alden, W. C., and Leighton, M. M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI, 1917. See pages 94-101.

character of the gumbotil very much, but the color was markedly altered. Over the soil was three feet of loess, the lower part gray mottled with brown, the upper part buff.

Other buried soils will be described in connection with the discussion of the Yarmouth loess and its age. Some of these may belong to the record of this interglacial time or perhaps may be the mark of some other part of the Buchanan interval.

Yarmouth Erosion

The Kansan drift is dissected by erosion. The dissection is shown by the dendritic character of the river systems, by the regular systems of major and minor valleys occupied by the streams and their tributaries, and by the complete drainage of the Kansan drift area. The features mentioned are not inherent in a newly glaciated surface. The apparent former extension of the Kansan gumbotil plain has been reduced by erosion. The gumbotil is found extending to the faces of the till slopes and there is cut off abruptly. On the surfaces of the till which are exposed below the gumbotil horizon there is commonly a concentrate of pebbles—a pebble band—from the thickness of a single layer of pebbles to several inches of gravel. The source of this material obviously is till from which the finer constituents have been removed either by water or wind erosion. In places a ferretto zone is found below the pebble band.

The erosion surface which the Kansan drift plain shows is not all of very recent creation. Much of the erosion occurred during the glacial and interglacial epochs since the Kansan glaciation. Some of this erosion occurred during Yarmouth time.

There is some evidence bearing on the amount of post-Kansan, pre-Illinoian erosion in Iowa, though most of it is indirect. Nowhere under the Illinoian drift in this state has the pre-Illinoian relief on the surface of the Kansan drift been extensively recognized. The amount of relief cut into the Kansan gumbotil plain at the beginning of the Illinoian glacial stage may be indicated by the comparative dissection of the Illinoian and the Kansan drifts, and by the magnitude and shape of the drainage lines on the Kansan drift surface which were modified by phenomena connected with the Illinoian ice invasion.

Comparative dissection of the Kansan and Illinoian gumbotil *plains.*—The comparative dissection of the Kansan and Illinoian gumbotil plains is not a true measure of pre-Illinoian erosion because of the difference in distance from Mississippi river of the areas for comparison, the difference in elevation of the gumbotil plains above the level of stream erosion, the difference in sizes of the streams performing the erosion, and the possible influence of rock barriers across the stream courses. However, the amount of erosion shown on the Kansan drift is distinctly different from that on the Illinoian, and as in general the Kansan drift is farther from the Mississippi than is the Illinoian, and its surface is lower, the greater erosion which the Kansan surface shows is truly an indication that it has been subjected longer to erosion than the Illinoian has been. But just how much longer, and therefore how much erosion was represented on the Kansan surface at the time of the Illinoian ice invasion, cannot be determined.

In adjacent areas of Illinoian and Kansan drift in southeastern Iowa, the Illinoian uplands are nearly twice as extensive as are the Kansan uplands. The character of the drainage also shows the surface of the Illinoian to have been for a shorter time under the developing influence of the stream waters.

Leverett[6] discusses the pre-Illinoian erosion of some of the streams in southeastern Iowa as follows:

"Definite means for determining the amount of pre-Illinoian erosion of the Kansan is afforded by a study of the valleys in Kansan drift which connect with the abandoned valley of the Mississippi, which was occupied at the Illinoian invasion. These embrace the valleys of West Crooked creek, Skunk river, and Big Cedar creek. Valleys farther north have generally been greatly modified by the Iowan invasion, and hence do not furnish good illustrations. It is found that the three valleys just noted have been cut at their points of connection with the abandoned valley to a depth of about 50 feet below neighboring uplands and to widths of about three-fourths of a mile, 1½ mile and 1 mile, respectively, at the time the Mississippi was occupying this abandoned channel, i.e., at the Illinoian stage of glaciation. This width is two or three times that of the inner valleys, which are now cut far below the level of the pre-Illinoian valleys, but represents nearly as much removal of material, and the removal was probably effected

6 Leverett, Frank, The Illinois Glacial Lobe: U. S. G. S. Monograph XXXVIII, pp. 121-122, 1899.

at a lower gradient, i.e., under less favorable conditions than are now afforded."

The Lake Calvin basin.—The Illinoian ice invaded Iowa from the east, crossing the present site of Mississippi river and forcing that stream to take a channel marginal to the ice and from ten to twenty-five or thirty miles west of its present course. Such displacement of the master stream resulted in disrupting the normal drainage through the tributaries as the blocking of the lower parts of the valleys necessitated the elevation of the water surface sufficiently for it to top the inter-stream divides, with the consequent ponding of some of the water in front of the ice dam. Probably several lakes were formed at this time, but all save one apparently were short lived. That one has been called Lake Calvin, of whose origin and history Schoewe has written.[7]

Lake Calvin was formed in the valleys of the Iowa and Cedar rivers. These two streams flow from the area of the Iowan drift south and eastward across the Kansan drift to unite at the edge of the Illinoian drift plain, flowing from there across the Illinoian drift plain southeastward to Mississippi river. It will be necessary to sketch briefly the history of these valleys that their bearing on the present problem may be developed.

Leighton summarized the history of Iowa river, in part, as follows:[8]

"At the time of the encroachment of the Kansan ice-sheet, the topography and drainage were entirely different from the topography and drainage of the present. A wide valley crossed the southern part of Johnson county, from west to east, and a notable rock divide lay to the northeast. This was covered by the Kansan ice, which, on melting, left drift which filled the low places and leveled off the high ones, producing a flat-lying plain. Upon this the surplus waters of the undrained depressions and surrounding areas sought the lowest outlet and ultimately established Iowa river. The course that the river now has is in general the course that marked the lowest outlet in the beginning.

"As Iowa river channeled its course deeper through the drift, it superimposed itself upon the rock-divides in the area of high bedrock.

7 Schoewe, Walter H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 49-222, 1925.

8 Leighton, M. M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV, pp. 103-181, 1916.

Having established its course it could not avoid them. The drift in the segment upstream and in the segment downstream from high bedrock, being much softer than the rock, offered extraordinary conditions for variable development of the valley. The resistance of the limestone permitted the river, in the upper segment of drift, to reach grade and to widen the valley by lateral planation while the gorge was being cut. In the segment downstream from bedrock, conditions worked differently, but the result was quite similar. The river cut so much more rapidly in the drift than it did in the rock that it reached grade sooner and had time to widen that segment to an old-aged stage of development.

"Contemporaneously with the carving of the valley, tributaries developed. Some of these tributary to the gorge cut considerably into rock whereas those tributary to the wide portions of the valley are cut mainly, if not altogether in drift. The result of the development of all these has been to dissect the original Kansan plain into many valleys and divides, and so completely to change its glacial aspect to an erosional one."

The history of Cedar river could be described in approximately the same terms with only a slight change in the location of the pre-Kansan bedrock divides and recognition of the fact that the post-Kansan Cedar river followed over a considerable part of its course a channel which had been cut in the bedrock prior to the invasion of the Kansan ice. Norton[9] suggests the dating of the Cedar valley in the following paragraph:

"The breadth and sloping sides of the wide reaches of the Cedar are evidences of great age, but in themselves alone these characteristics do not imply a preglacial or pre-Kansan origin. Valleys as broad in southwestern Iowa have been found to be post-Kansan by the geologists who have studied that field. But, while the latter are cut in drift, the former are cut in solid rock in large measure. Taking into consideration both the quantity and the hardness of the material excavated, and, in especial, the fact that the drift lies unconformable on the slopes of rock which form the sides of the valley, the conclusion is inevitable that the wide (bedrock) valleys of the Cedar are at least pre-Kansan in age, and may, perhaps, be even preglacial."

Three stages in the history of the Iowa and Cedar river valleys are of significance in the present discussion. The first stage is that following the formation of the Kansan gumbotil, when

9 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 291, 1901.

the dissection of the Kansan gumbotil plain occurred. The second stage was marked by the ponding of the waters in front of the Illinoian ice to form Lake Calvin. The third stage records the Iowan glaciation and its influence on the lake basin and the rivers.

The first stage mentioned above has been summarized already. A mature dissection of the Kansan surface developed while the

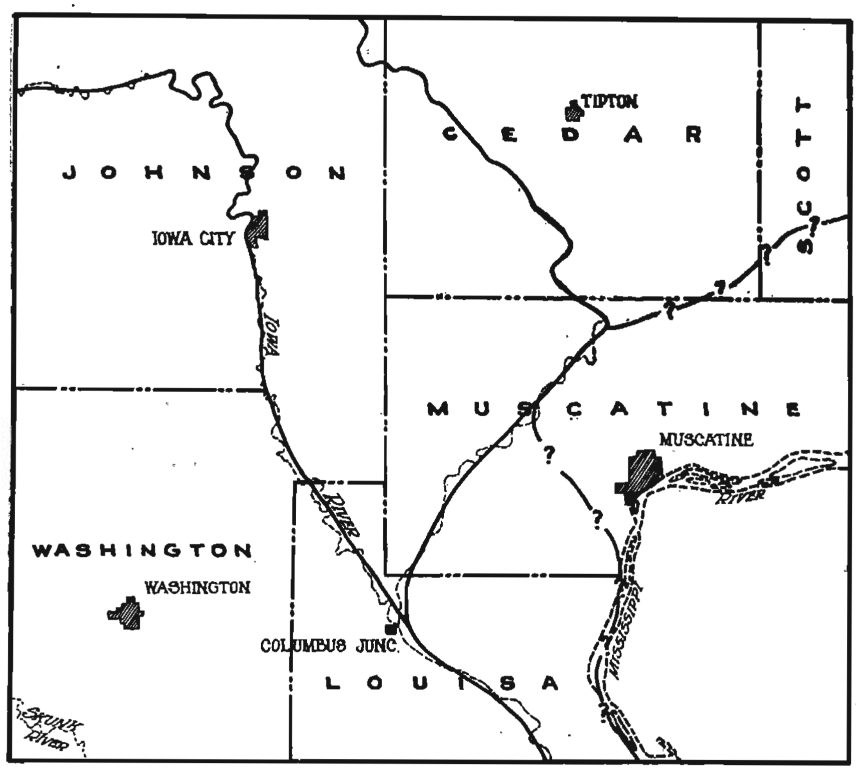

FIG. 60.—Sketch map of the Lake Calvin area showing probable drainage lines across the Kansan dissected gumbotil plain in pre-Illinoian time.

drainage of the Kansan gumbotil plain followed somewhat the lines indicated in figure 60.

The second stage of the history of this region is shown in figure 61. The coming of the Illinoian ice blocked the lower courses of the eastward flowing tributaries to the Mississippi, and caused the master stream itself to flow around the western edge of the ice front. Lake Calvin was formed at this time, and in this lake were deposited the characteristic lake materials from the various sources available to the streams flowing into the lake, including those coming from the glacial ice itself. Bluffs were formed by the sapping of the shore by the waves; deltas were built of the detritus brought in by streams; and the finer material from all sources settled in the more quiet lake waters to build up the bed.

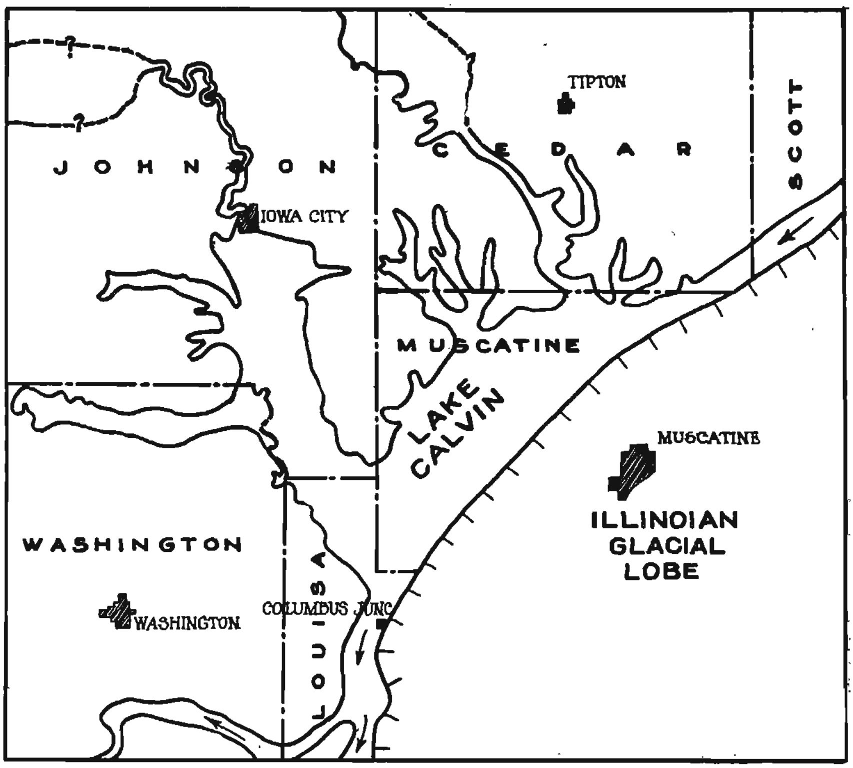

FIG. 61.—Sketch map of the Lake Calvin area showing the accommodation of the drainage to the blocking by the Illinoian ice.

When the lake was drained, these features persisted as marks of the former occupation of this area by lake waters.

The draining of Lake Calvin occurred very shortly before the third stage in the history of the lake area. New conditions were created by the advent of the Iowan ice sheet, which inaugurated the last stage of the history with which we are here concerned. Figure 62 shows the drainage relationships which existed during the third stage.

The drainage lines which crossed the lake floor after it was drained cut valleys into the filling which had been deposited while the lake was in existence, leaving the terraces along the sides of the streams. Melt waters from the Iowan glacial ice, loaded with débris as they were, became depositing streams in the area where the lake floor had been dissected, building up the stream beds to new levels. When the supply of material and

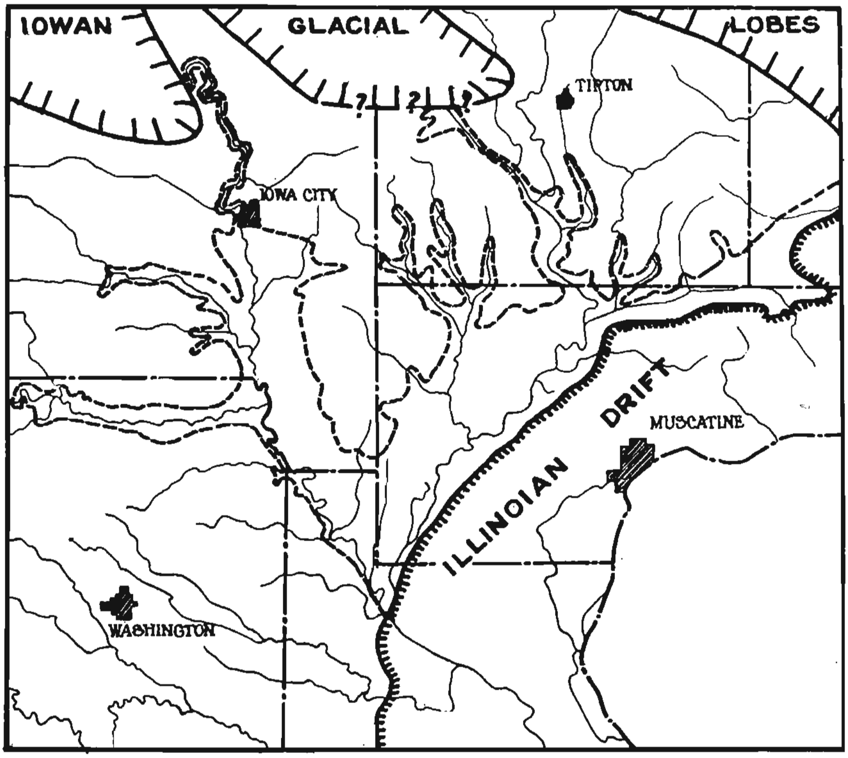

FIG. 62.—Sketch map of the Lake Calvin area showing the drainage during the time of the Iowan glaciation.

amount of water decreased with the melting away of the Iowan ice, the streams again became eroding streams, cutting into the newly deposited sand and gravel, leaving remnants of this material to form a new terrace at a level lower than that of the terrace formed by the remaining parts of the bottom of the old lake.

Iowa and Cedar river valleys bear, in their several parts, the marks of the three stages of history described above. The midpart of the valley is post-Kansan in age and is partly filled with detritus brought into the lake during Illinoian time. The lower parts of the valleys were covered by the Illinoian drift, and their present form is therefore of post-Illinoian development. The upper parts of the valleys were covered and modified by Iowan ice and its deposits.

The Iowa and Cedar river valleys, where they were occupied by Lake Calvin, represent depressions in existence prior to the blocking of the channel of the pre-Illinoian Mississippi river by the Illinoian ice. That these valleys were to a great extent erosional valleys is attested by the uniformity of the upland levels around the lake basin, on which levels the Kansan gumbotil was developed. In the immediate vicinity of the valley walls the dissection was so great that very little of the gumbotil is left. Enough gumbotil outcrops have been found to show that the plain had an elevation of about 750 feet in the western part of the lake area and 670 feet in the eastern part, beneath the Illinoian drift.[10]

The Lake Calvin basin, because it was made by post-Kansan-gumbotil erosion, even though it was partly filled by lake deposits during Illinoian glacial time, is a measure of the dissection of the Kansan drift in Yarmouth time. The depression is a marked one. The amount of dissection which this depression has undergone since it has been subjected to erosion in post-lake time is not great, certainly not quantitatively as great as the amount of filling which occurred during the occupation by the lake water.

The western, or Iowa river arm of the lake basin is about twenty-eight miles long and over this distance has an average width of four and four-tenths miles. The eastern, or Cedar river arm of the lake is about twenty-four miles long and has an average width of five and eight-tenths miles. Tributary valleys which show that they were in existence and became a part of Lake Calvin during Illinoian time are: English river valley, which shows lake influence for a distance of fifteen miles up its valley, which is half a mile wide; Old Mans creek, which has lake deposits for ten miles along a valley somewhat over a mile wide; Wilton valley, which shows lake influence for eight and one-half miles above Moscow over a floor which is a mile to two miles wide.[11] The depth of the depressions averages between eighty

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10 Schoewe, Walter H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, p. 98, 1925.

11 Schoewe, Ibid., p. 109.

and one hundred feet, but ranges between forty or less and about one hundred and forty feet between the terraces and the level of the Kansan plain.

The amount of erosion represented by these valleys cut in Yarmouth time is a measure of a long interval, even though the cutting took place almost wholly in glacial materials. The dissection is in some areas almost comparable in amount, though the relief is not as great, with the dissection of the Nebraskan drift before the coming of the Kansan ice. More of the divide areas show the Kansan gumbotil, perhaps because of the lesser relief with its consequently slower reduction of the upland level to form valley slopes.

Silts and Sands

The deposition of beds of silt and sand may and commonly does take place under temporary conditions. Conditions under which these deposits could be made would occur with the coming of the Illinoian ice into Iowa, blocking the drainage of the Mississippi and its tributaries. Silts and sands deposited in such ponded waters would be early Illinoian in age, rather than Yarmouth, but they would underlie the Illinoian till. In and near Muscatine several deposits of silts and sand have been found, some of which may be of the origin just stated. Udden[12] described a series of silts, leached and unleached, which he designated "ante-glacial". Of the origin of this material he says:

"It will be noted that in each of the above described localities the bedrock appears close by, usually not more than two or three rods away. In all but two places the formation lies in preglacial valleys now partially filled with drift. In four cases it is seen to be overlain by the lowermost drift known in the region presently to be described. For the most part it is calcareous and frequently it is plainly water bedded. Sometimes it graduates into drift. At other times it is disturbed by glacial action and partly worked into the boulder-bearing drift. In four places it contains a layer that resembles a marshy soil, with plants, snail shells and some peaty material.

"It seems most likely that this silt and loess accumulated in front of the margin of the first ice field. The prevailing calcareous nature of the thin-bedded silts indicates such a source. The plainly marked lamination of these shows that their deposition was comparatively

12 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 328-332, 1899.

rapid. . . . Occasionally loess-like wind drift might also accumulate in such situations. The advancing ice may later have overrun and disturbed such deposits, plowing them up and mixing them with drift in places, and at other places leaving them undisturbed in the position in which they are now found. . . . Possibly a part of them may be preglacial loess."

These materials may be in part Yarmouth or early Illinoian in age. The ponding of drainage waters by the Illinoian ice would have made almost ideal conditions for the accumulation of the types of materials which are described.

Thick and extensive silts and sands in western Iowa are related in age to the loess which has been called Loveland. These deposits will be described in a section devoted to the Loveland formation.

The Loveland Formation

In 1909 Shimek[13] named a formation "consisting of heavy clay resembling somewhat the drift joint-clays," the *Loveland.* He described this material and stated that it was of aqueous origin. He found it "as widely distributed as the Kansan drift."[14]

Study of the type section of the Loveland and of many other sections in the field and of the clay in the laboratory has led to the conclusion that this material is an old loess.[15] There are associated with this loess sands and silts of similar age, differing only in origin from the loess. These silts and sands, together with the loess, constitute the *Loveland formation,* and the time within which their deposition took place is the Loveland interval.

The Loveland formation rests upon the eroded surface of the Kansan gumbotil plain. The Loveland interval therefore began not earlier than late Yarmouth time, as the gumbotil had been formed and the mature dissection of the drift plain had occurred before the Loveland was laid down. This formation is in many places leached, and some of the materials show alteration beyond the mere removal of the more soluble constituents. A

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13 Shimek, B., Aftonian Sands and Gravels in Western Iowa: Bull. Geol. Soc. Am., Vol. 20, Footnote, p. 405, 1909.

14 Shimek, B., Geology of Harrison and Monona Counties: Iowa Geol. Survey, Vol. XX, pp. 371-375, 1910.

15 Kay, G. F., Loveland Loess: Post-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. LXVIII, pp. 482-483, Nov. 16, 1928. Also, Significance of Post-Illinoian, Pre-Iowan Loess: Science, N. S., Vol. LXX, pp. 259, 260, Sept. 13, 1929.

young loess, commonly unleached, overlies the Loveland in most places, indicating that the alteration of the Loveland loess and silts occurred before the deposition of the overlying material. As the loess resting upon the Loveland is in part at least Peorian in age, the close of the Loveland interval preceded that interglacial stage. The Loveland interval is a part of the Buchanan interval. The deposition of a part of the Loveland may have taken place during Yarmouth time, but the exact extent to which the Loveland formation represents that interglacial stage has not yet been determined.

The loess of the Loveland formation is widely distributed, having been found in most parts of the state. The type section was described from Loveland, in northwestern Pottawattamie county, where the loess rests upon eleven feet of oxidized and unleached till over bluish gray unweathered till. Here the Loveland loess is covered with thick buff loess, most of which is Peorian in age. Both loesses are fossiliferous, fossils being more abundant in the Peorian loess than in the Loveland.

There is an excellent exposure of old loess in a railroad cut just east of McPherson station on the Chicago, Burlington & Quincy railroad in Montgomery county. More than twenty feet of leached Loveland loess is exposed under twenty-five feet of calcareous buff loess. The base of the old loess was not seen in this cut, but west of the station the Loveland loess lies upon oxidized and leached Kansan till.

Another excellent section showing Loveland loess was found in northwestern Iowa in a road cut along the northwest quarter of section 32, Henry township (T. 91 N., R. 43 W.), Plymouth county. Eight feet of highly calcareous buff loess, the lower part of which is sandy, overlies three feet of leached, brownish gray loess, in which is carbonaceous matter. The buff loess is filled with concretions, and there are a few concretions of secondary calcium carbonate in the upper part of the leached loess. The base of the Loveland loess is not exposed in this cut, but in another cut about forty rods to the south the same sequence of materials was observed overlying unoxidized and unleached till.

The Loveland loess in northwestern Iowa is pre-Iowan in age as is shown by the following section along the road between sections 4 and 9, Carroll township (T. 96 N., R. 42 W.), O'Brien county:

		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

The finding of the Loveland loess beneath Iowan till dates it as certainly older than the formation of that till.

The Loveland loess lies on Kansan gumbotil in a cut between sections 15 and 22, Cass township (T. 79 N., R. 40 W.), Shelby county. A photograph of this cut is shown in figure 63. A section in the cut is as follows:

		Feet
3.	Loess, Peorian, upper part buff in color, grading down into gray loess which has some iron stains, and in which are iron tubules, leached	12
2.	Loess, Loveland, leached, brownish gray in upper part, lower part much lighter in color with numerous brownish yellow stains. Distinctly different from the material above and below	4
1.	Gumbotil, Kansan, dark gray to brown, upper part shows considerable secondary calcium carbonate in places, mass is leached; exposed	3

The same relationships were seen in a section a few miles east in a road cut between sections 16 and 21, Lincoln township (T. 79 N., R. 39 W.), Shelby county. In this place the Peorian loess was seven feet thick, the Loveland loess was three feet thick, and the Kansan gumbotil was exposed for a thickness of two feet.

The Iowan till of northeastern Iowa overlies Loveland loess at several places, some of which are: between sections 28 and 29, Hazel Green township (T. 87 N., R. 5 W.), Delaware county; along the north line of section 16, Windsor township (T. 94 N., R. 9 W.), Fayette county; and between sections 10 and 11, Lincoln township (T. 87 N., R. 14 W.), Black Hawk county. In each of these places the Loveland lies over Kansan gumbotil, and in the last two places it rests upon a soil band on the gumbotil. The Fayette county section has been described in detail on page 230, in the chapter on the Kansan drift. The section in Black Hawk county is as follows:

		Feet	Inches
4.	Loess and sandy loess, Peorian	2	
3.	Till, Iowan, sandy and pebbly, leached	1	
2.	Loess, Loveland, gray, irregularly laminated, with the laminæ showing some distortion		6 to 8

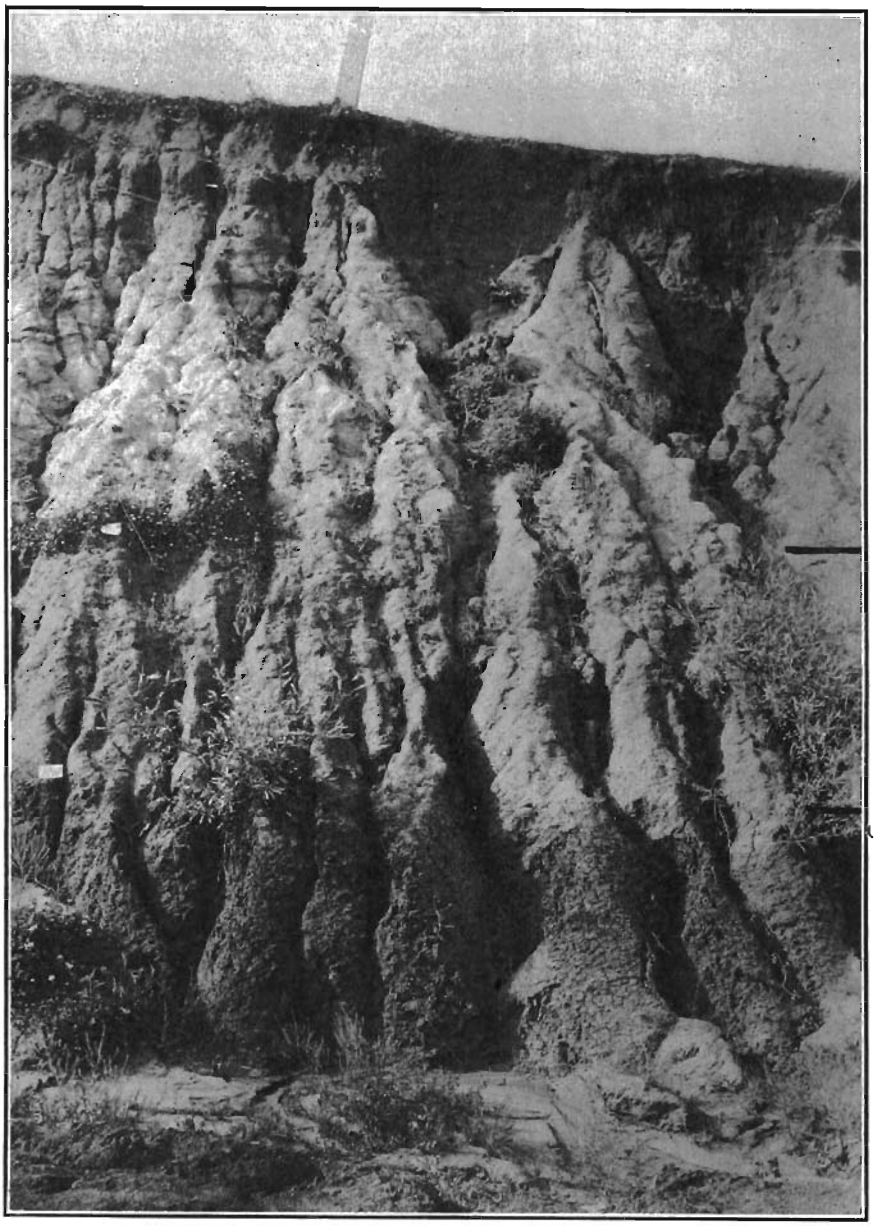


FIG. 63.—Kansan gumbotil (at the base), Loveland loess, and Peorian loess in Shelby county. The marks show the limits of each kind of material.

1.	b) Very dark gray carbonaceous soil zone which is related to the material below		6
	a) Gumbotil, Kansan, typical in color, texture and structure; exposed	5	

East of the area of the Iowan till in northeastern Iowa there is Loveland loess beneath the thicker loess over the Kansan drift border. It was observed in a cut in the northwest quarter of section 23, Monmouth township (T. 84 N., R. 1 E.), Jackson county. In this cut there is very highly ferruginous, leached drift lying upon bedrock and overlain with about twenty-five feet of gray and buff unleached loess. At the east end of the cut the drift was absent, but resting upon the rock was one and one-half feet of red leached Loveland loess under the unleached loess.

The loess of the Loveland consists of fine sand and silt in a clayey matrix which in mechanical analysis is very much like the buff loess which overlies it. The one difference is the slightly higher percentage of very fine material in the Loveland loess than in the buff loess. However, weathering would tend to make this modification of the loess, and the older loess is uniformly more weathered than the buff loess of Peorian age.

Record of Life in the Yarmouth

The record of Yarmouth life in Iowa is very poorly representative of the fauna and flora which must have inhabited this area during the second interglacial stage. Numerous invertebrates and some vertebrates have been identified from Iowa as belonging to this interglacial stage, but the accuracy of the interpretation of the age of many of the fossil-bearing deposits is open to question. From other areas an extensive fauna is known, and from Iowa as well as from other areas a flora of some variety has been recognized as of Yarmouth age. The available faunal and floral lists, and a catalog of the vertebrate animals are found in the works of Hay[16] and of Baker[17] to which previous reference has been made.

16 Hay, O. P., The Pleistocene of the Middle Region and its Vertebrated Animals: Carnegie Institution of Washington, Pub. No. 322A, 1924.

17 Baker, F. C., The Life of the Pleistocene or Glacial Period: Univ. of Illinois, 1920.

CONCLUDING STATEMENTS

The results of field and laboratory studies extending over many years have been presented. The senior author has examined during the summer months of the past eighteen years hundreds of road cuts which were made in grading more than 15,000 miles of primary and secondary roads of the state. The junior author assisted in the field in collecting several hundred specimens representing the different kinds of glacial and interglacial materials of Pleistocene age. These specimens were subjected by the junior author to detailed analytical study in a laboratory equipped for the investigation of sediments by modern methods.

As an adequate background for the most satisfactory presentation of the pre-Illinoian Pleistocene geology there have been included chapters on the Bedrock Surface of Iowa, the Topography and Drainage of Iowa, and the History of Investigations and Classifications of the Pleistocene Deposits of Iowa. It is hoped that the views of the many persons who have made distinct contributions to our present knowledge of the Pleistocene geology of the state have been given with sufficient fullness to properly represent them.

In Chapter I, which deals with the bedrock surface of Iowa, it has been stated that the available evidence seems to warrant the interpretation that the pre-Pleistocene surface over which the first ice sheet advanced had a topography characteristic of a mature erosional surface, with broad valleys, moderate slopes, a complete drainage system, and a relief of approximately 400 feet. The steep-walled drift-buried valleys which are distinctive features of the bedrock topography are interpreted to have been cut not in pre-Pleistocene time as has been held generally but chiefly in Aftonian interglacial time.

The Nebraskan glacial stage and the succeeding interglacial stage, the Aftonian, have been treated in separate chapters. This has resulted of necessity in some overlapping in the consideration of certain features of the deposits and of the histories of these two stages. The same statement should be made with regard to the separate chapters on the Kansan glacial stage and the Yarmouth interglacial stage. Only when the discussion of a glacial stage and the interglacial stage which follows it are considered together is it possible to get a proper understanding of each of the stages.

With regard to the names now being used for the two oldest drifts, namely, Nebraskan and Kansan, it is a fact that if priority of usage of terms were adhered to strictly in the classification of the Pleistocene the names Kansan drift and Iowan drift would be the proper names for the two oldest drifts since these names were given by Chamberlin in 1894 to the present Nebraskan drift and Kansan drift, respectively, in the well known Afton Junction region in Union county. But later, for reasons set forth in Chapter III of this report, the name Kansan was transferred to the upper of the two tills at Afton Junction and the name Pre-Kansan or Sub-Aftonian was given to the older of the two drifts at that place. From then on the name Iowan has been restricted to the Upper Till of McGee in northeastern Iowa, and in recent years to a till of the same age in northwestern Iowa. Then in 1909 the name Nebraskan was given to the Pre-Kansan or Sub-Aftonian drift. Since that time the name Nebraskan has become well established by usage in publications not only of the Iowa Geological Survey but of the United States Geological Survey and in many papers in magazines and journals in America and in foreign countries. During the brief interval between the time of publication of Geikie's Great Ice Age, in which the names Kansan and Iowan were first used by Chamberlin for the two oldest tills in the Afton Junction region, and the renaming of these two tills by Iowa geologists only a few papers dealing with Mississippi Valley Pleistocene geology appeared. On the other hand, during the more than thirty years since the shift in names was made, Kansan and Iowan have been used hundreds, perhaps thousands, of times by many writers and in many kinds of publications in the United States and elsewhere. The many textbooks which have discussed the classification of American Pleistocene deposits have used the names Kansan and Iowan in accordance with present practice. Regardless of the weight of evidence with respect to priority of the terms Kansan and Iowan for the two oldest drifts it would seem to be best from the standpoint of long usage to continue to use the names as they have now been used for so long a time. This point of view may be urged with seeming propriety since a study of the record shows that all persons who were familiar with the basis of change acquiesced in the change at the time that it was made. To revert now to the original usage would result in endless confusion and most serious inconvenience.

The first ice sheet, the Nebraskan, covered all of Iowa and deposited a drift which has been estimated to have had probably an average thickness of more than 100 feet, possibly as much as 150 feet. In northeastern Iowa there is an area which only a few years ago was included in the Driftless Area but within which there are now known to be patches of drift which are interpreted to be Nebraskan in age. The Nebraskan drift is now at the surface only within restricted areas, as it is overlain in many places by younger drift or by loess. A map on which the areal distribution of the Nebraskan drift is shown for the first time is included in this report (Plate II). In many parts of the state the Nebraskan drift closely resembles the Kansan drift. Only locally can the Nebraskan drift be differentiated lithologically from the Kansan drift. In fact, the only satisfactory basis found thus far in Iowa upon which to decide definitely whether a pre-Illinoian till is Nebraskan till or Kansan till is the relationship of the till to interglacial materials the age of which can be determined. Among the most widespread of interglacial materials is gumbotil, the characteristics, topographic position, and origin of which have been presented fully in this report. If a till is overlain by Nebraskan gumbotil or can be shown to be related to Nebraskan gumbotil, which in Iowa is found as remnants of a former extensive Nebraskan gumbotil plain, the till is Nebraskan till. If, however, the till is overlain by Kansan gumbotil or can be shown to be related to Kansan gumbotil, which also is found as remnants of a former extensive Kansan gumbotil plain, the till is Kansan till. As shown in this paper, the gumbotils on account of their distinctive characters, wide distribution, and topographic positions, are the most satisfactory criteria that have been found for differentiating the older drifts in Iowa. Furthermore, since the gumbotils are the result of changes which took place in interglacial times they may be considered in relation to the problem of the relative durations of the interglacial epochs. The thicker the gumbotils the greater the time involved in their development. During the Aftonian interglacial epoch the Nebraskan drift underwent many changes. The unoxidized and unleached Nebraskan till where so situated that weathering was effective and erosion was negligible was changed stage by stage until Nebraskan gumbotil was formed to an average thickness of more than eight feet.

Gravels of Nebraskan age are associated with the Nebraskan till. Where these gravels were subjected to weathering throughout Aftonian time they underwent great chemical changes, comparable to the changes which till underwent to produce gumbotil. Lenses and irregularly shaped masses of gravels incorporated in the Nebraskan till are weathered but little. They are unleached of their lime but are in most cases somewhat oxidized.

The second ice sheet, the Kansan, covered all of Iowa except a comparatively small area in the northeastern corner of the state. (See Plate II.) The drift deposited by this ice sheet has been estimated from field evidence to have had an average thickness above the elevation of the Nebraskan gumbotil plain of probably less than fifty feet. When to this figure is added the drift necessary to fill the valleys cut in the Nebraskan drift surface the Kansan drift is seen to be also a massive drift to be ranked with the Nebraskan as one of the great drifts of the Pleistocene of the state. During the Yarmouth interglacial epoch the Kansan drift underwent changes similar to the changes which the Nebraskan drift underwent in Aftonian time. On the Kansan there was developed a gumbotil with maximum thickness of fifteen feet and average thickness of more than eleven feet. Gravels of Kansan age where they were subjected to weathering under conditions similar to the conditions which resulted in Kansan till being changed to gumbotil became strongly oxidized and deeply leached. Within the Kansan till also there are lenses and irregularly shaped masses of gravels resembling closely the fresh gravels in the Nebraskan drift.

The laboratory studies of the Nebraskan and Kansan gumbotils, the oxidized and leached Nebraskan and Kansan tills, the oxidized and unleached Nebraskan and Kansan tills, and the unoxidized and unleached Nebraskan and Kansan tills strengthen the interpretation that all of the phases of each of these tills are related in origin.

The mapping of the outcrops of Nebraskan and Kansan gumbotils has demonstrated that these gumbotils are the most satisfactory horizon markers in the state. They have been useful not only in differentiating the Nebraskan drift from the Kansan drift but in mapping these two drifts. Inspection of Figures 26 and 27 will reveal the significance of this statement.

Peats and weathered gravels have been and will continue to be of value in interpreting Aftonian and Yarmouth interglacial history but they have been found to be less serviceable than the gumbotils in areal mapping in Iowa. Only a few good peat exposures of Aftonian age have been found in the whole state and these are separated widely from one another. Nor are there many good exposures of peat of Yarmouth age. Moreover, since gravels differ in origin, in composition, in topographic position, in degree of weathering, and in other respects, their use in mapping is somewhat restricted. Much less reliance is now placed upon interpretations of gravels and "forest beds" penetrated in well drillings than was given to these materials in the earlier years of Pleistocene studies.

The Nebraskan gumbotil is widespread in southwestern Iowa; in fact, from these gumbotil outcrops it has been possible to map areally the Nebraskan drift of this region. Figure 26 shows that Nebraskan gumbotil extends into the northwestern part of the state and that comparatively few outcrops of this gumbotil have been found within the Iowan area of northeastern Iowa or in southeastern Iowa. The mapping of the outcrops of Nebraskan gumbotil and Kansan gumbotil has impressed the fact that the original Nebraskan gumbotil plain and the original Kansan gumbotil plain were widespread in the state. It is somewhat surprising to find that so much of each of these plains has escaped erosion. Remnants of the Kansan gumbotil plain are a striking feature of the topography of the Kansan drift area of southern Iowa, where they are known as tabular divides.

This report deals chiefly with the geology of the pre-Illinoian part of the Pleistocene of Iowa. However, there has been no hesitation in weaving into the discussions any facts about Illinoian and post-Illinoian Pleistocene geology whenever it was thought that by so doing the reader would be able to get a better understanding than otherwise would be possible of the early glacial and interglacial epochs of Pleistocene time.

The relations of the pre-Illinoian Pleistocene to the Illinoian and post-Illinoian Pleistocene in different parts of the state are represented diagrammatically in Plate III. In this diagram the different phases of Nebraskan and Kansan drifts are indicated, including the unoxidized and unleached tills, the oxidized and unleached tills, the oxidized and leached tills, and the gumbotils. Within each of these two tills inclusions of gravels are shown, also Nebraskan and Kansan gravels at the elevations of the Nebraskan and Kansan gumbotils, respectively; also Aftonian and Yarmouth interglacial deposits. The diagram represents the fact that the gumbotils on the Nebraskan and Kansan tills are much thicker than the gumbotil on the Illinoian till and that no gumbotil has developed on either the Iowan or Wisconsin tills. No loess separating the Nebraskan drift from the Kansan drift is indicated. Silts have been found in a few places at this horizon, but no deposit which has been interpreted to be definitely of eolian origin. Nor does the diagram show a loess between the Kansan and Illinoian tills because no good sections of loess overlying Kansan drift and underlying Illinoian drift have been found thus far in Iowa although on the Illinois side of Mississippi river a pre-Illinoian loess is known in several places. Two loesses are shown, the Loveland loess and the Peorian loess. In the northwestern part of the state within the area where Iowan drift has been mapped the Loveland loess and related materials are lying on the post-Kansan-gumbotil erosion surface and beneath the Iowan till. The Peorian loess here mantles the Iowan drift. In the northcentral part of the state the relations of the two loesses to the Kansan and Iowan tills are the same as in northwestern Iowa. Within the Wisconsin drift area the Peorian loess lies under the Wisconsin drift. Where the Iowan drift is absent in the northwestern, western, and southern parts of the state, the Peorian loess lies directly upon the Loveland loess and related deposits wherever the Loveland is present.

Within the Illinoian drift area of southeastern Iowa there are two loesses on the Illinoian drift, the older of which has been correlated with the Loveland.[1] Mr. Frank Leverett, however, correlates the Loveland loess of western Iowa with pre-Illinoian loess and questions the existence of a post-Illinoian, pre-Peorian loess.[2] But recently this loess has been mapped widely by members of the Illinois and Iowa Geological Surveys. Although the Loveland loess of western, central and southern Iowa appears to be a single formation, in reality its lower part may be pre-Illinoian in age, and only its upper part post-Illinoian in age; and it may be that a part of the Loveland loess of western, central, and southern Iowa was deposited during the Illinoian glacial epoch. If this interpretation should prove to be a correct one then the post-Illinoian, pre-Peorian loess would be equivalent to only a part of the Loveland of western Iowa and should be given a name different from Loveland. The significance of the post-Illinoian, pre-Peorian loess in relation to the relative ages of the Iowan and Illinoian drifts has been emphasized recently.[3]

The evidence warrants the interpretation that the Aftonian and Yarmouth interglacial epochs were of long duration. The Sangamon interglacial epoch; although long, was much shorter than the Aftonian or the Yarmouth. By far the shortest interglacial epoch was the Peorian. The chief material deposited in Iowa during the Peorian interglacial epoch was loess, which has been determined to have been deposited very soon after the retreat of the Iowan ice sheet. The evidence indicates that this loess underwent no marked change before it was overridden by the Wisconsin ice sheet.

If one dare make a prediction it would be to the effect that future investigations of the Pleistocene deposits of Iowa are likely not to weaken but to strengthen the now generally accepted view that the Nebraskan, Kansan, and Illinoian glacial epochs were separated widely in time, that the Iowan glacial epoch was much younger than the Illinoian glacial epoch, and that the Iowan and Wisconsin glacial epochs were much more closely related in time than were any other two of the epochs. The Wis-

1 Kay, G. F., Loveland Loess: Post-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. LXVIII, pp. 482-483, Nov. 16, 1928.

2 Leverett, Frank, Loveland Loess: Pre-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. LXIX, pp. 551-552, May 24, 1929.

3 Kay, G. F., Significance of Post-Illinoian, Pre-Iowan Loess: Science, N. S., Vol. LXX, pp. 259, 260, Sept. 13, 1929.

PLEISTOCENE
OF
IOWA

WISCONSIN

PEORIAN

IOWAN

SANGAMON*

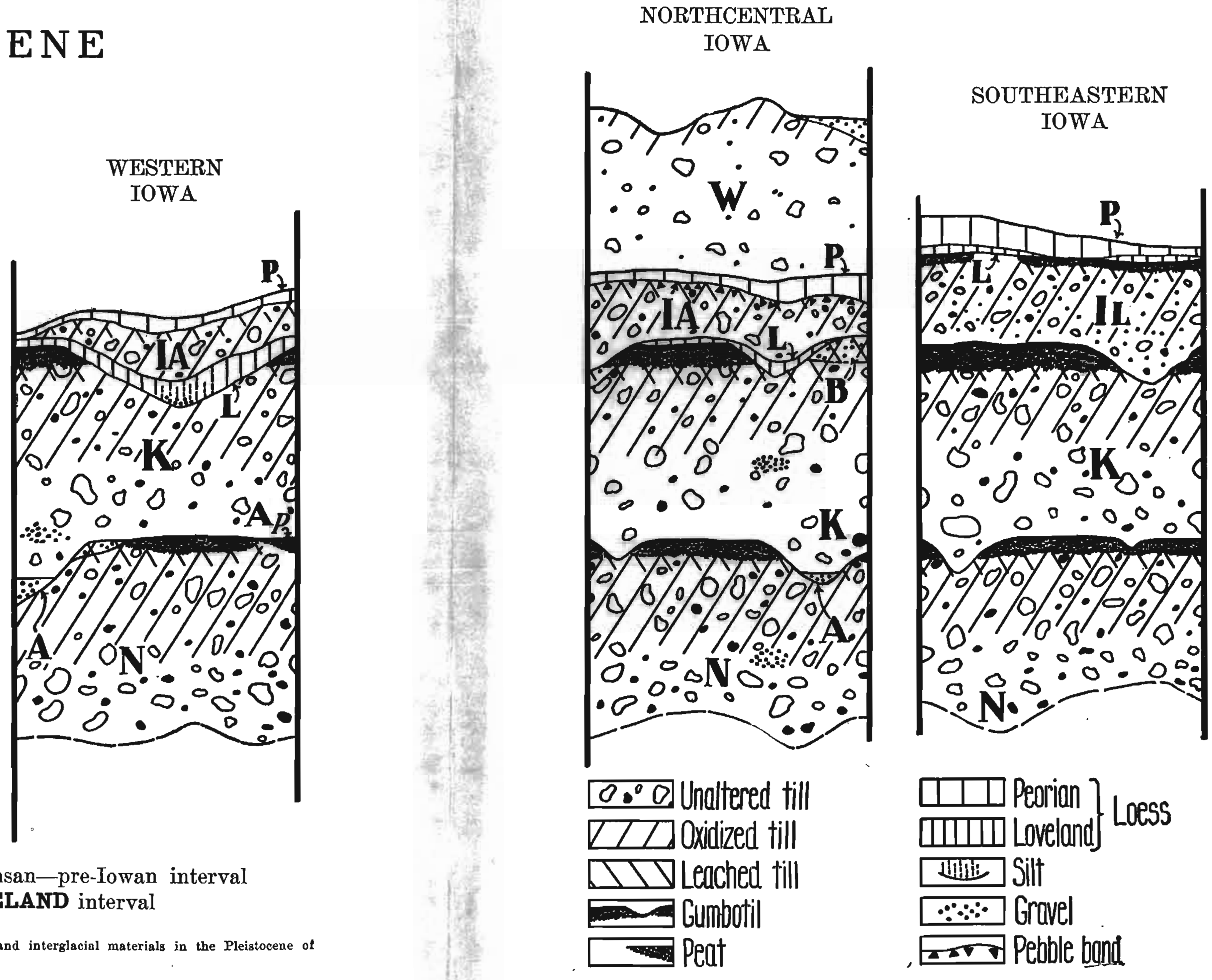
ILLINOIAN*

YARMOUTH*

KANSAN

AFTONIAN

NEBRASKAN



***BUCHANAN**—Post-Kansan—pre-Iowan interval including **LOVELAND** interval

PLATE III. Diagrammatic sections of glacial and interglacial materials in the Pleistocene of Iowa.

consin and Iowan drifts have characters as distinctive as are the characters of other glacial stages, and hence each of them will continue to have separate recognition in Pleistocene classification. Five glacial and four interglacial stages will continue to be recognized in the classification of the Pleistocene deposits of Iowa.

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 the 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.

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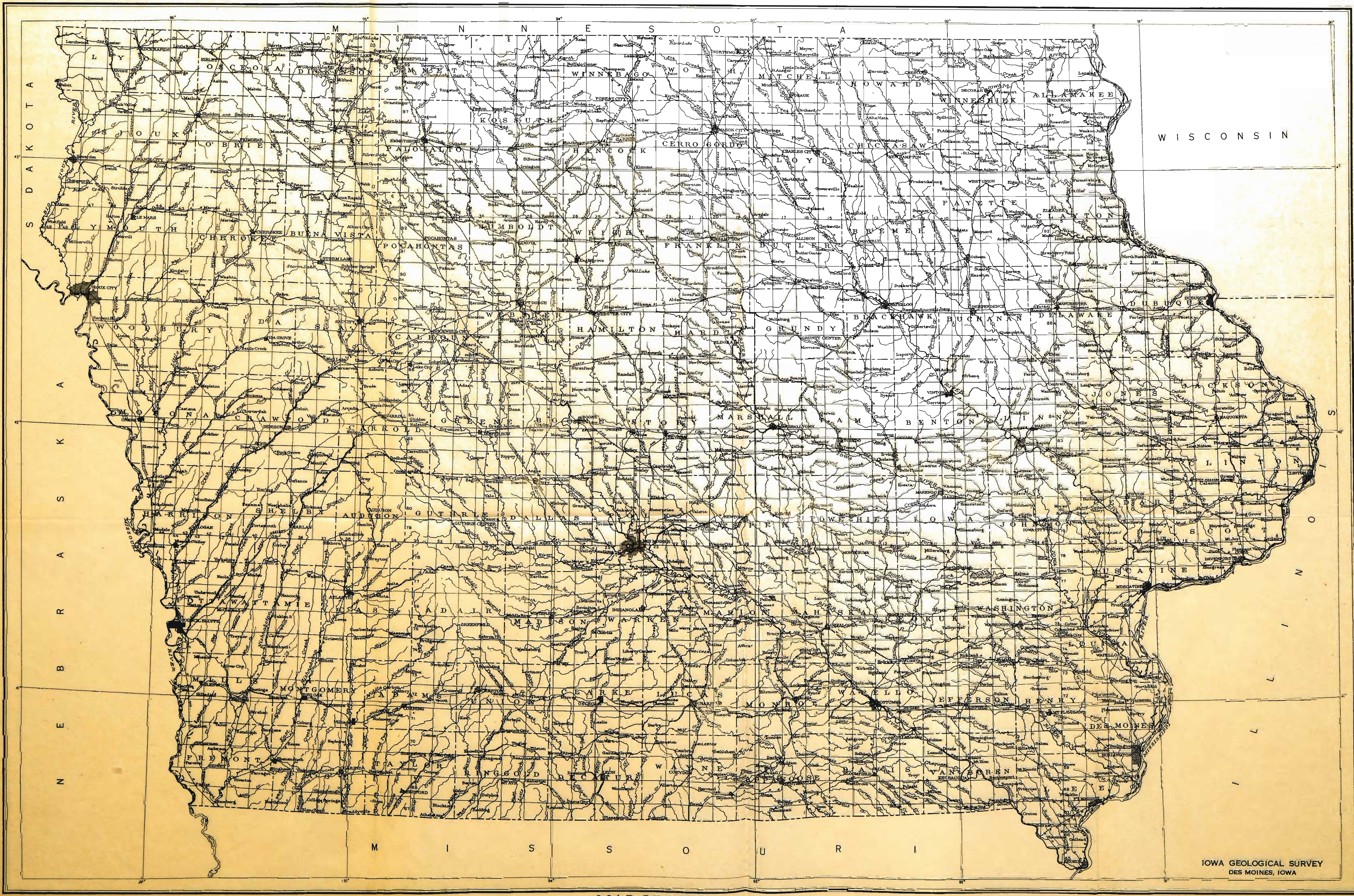

MAP OF IOWA

Scale 1/500000

Miles

THE STRATIGRAPHY AND PALEONTOLOGY

of the

MAQUOKETA SHALE OF IOWA

PART I

by

HARRY STEPHEN LADD

CONTENTS

LIST OF ILLUSTRATIONS

THE MAQUOKETA SHALE OF IOWA

PART I

Abstract

This paper constitutes Part One of a report upon the stratigraphy and paleontology of the Maquoketa shale of Iowa. In it the stratigraphic relations are discussed and the important faunal zones are described. Part Two will appear later and will consist almost entirely of descriptions of fossils.

The Maquoketa shale, an Ordovician formation widely exposed at a number of places in the Mississippi valley, covers an area of nearly 700 square miles in northeastern Iowa. The Iowa area is divided into two parts on the basis of lithologic differences, with which are associated faunal differences. These subdivisions are referred to as the *Northwest Area* and the *Southeast Area,* the type locality of the formation being found in the latter. The distribution and characteristics of the formation as seen in these two areas are fully described. In the Southeast Area the section is a lithologic unit, being composed almost entirely of blue-green shale. In the Northwest Area four members are recognized which, in ascending order, are as follows: (1) the Elgin shaly limestones, (2) the Clermont shale, (3) the Fort Atkinson limestone, and (4) the Brainard shales.

The Maquoketa is underlain unconformably by older Ordovician rocks. The physical evidence of an interval of emergence and erosion is very obscure, but the thickness and distribution of immediately older Ordovician beds elsewhere practically establishes unconformity by overlap. To support this there are striking faunal and lithologic changes. The Maquoketa is overlapped by five younger Paleozoic formations ranging in age from Alexandrian (Silurian) to Pennsylvanian. At the contact with each of these formations there is some evidence of post-Maquoketa erosion.

The question of the age of the Maquoketa (Richmond) is briefly discussed. The author believes that it should be placed in the Silurian but pending the completion of studies of beds just below

the Maquoketa of Iowa the formation is retained in the Ordovician.

The lower portion of the Richmond of Michigan is seen to be almost identical with the lower portion of the Maquoketa in the type locality. Possible correlations with the Richmond of the Ohio valley are discussed. It is suggested that the Depauperate zone at the base of the Maquoketa is equivalent to a very similar zone at the top of the Arnheim, lowest member of the Richmond in the Ohio valley. The Cornulites zone at the top of the Maquoketa is correlated with the Elkhorn of the Ohio valley.

Three of the faunal zones described are shown to be developed in both areas in Iowa—(1) the Depauperate zone at the base of the formation, (2) a Graptolite zone near the base and (3) the Cornulites zone at the top. Twenty-seven additional species, of which ten are new, have been identified from the Depauperate zone. This brings the total number of species known from this horizon to 44, over half of which are molluscs. The assemblage is made up of unusually small species but they are not true dwarfs. Several explanations, none of which is entirely satisfactory, are suggested to account for this smallness.

In the Northwest Area the Graptolite zone occurs almost immediately above the Depauperate zone but in the Southeast Area it is separated from the Depauperate zone by about 40 feet of barren beds. The Cornulites zone carries a fauna of 86 species of which 69 are molluscoids.

Other faunas are developed only in the Northwest Area. Tables showing the horizontal and vertical range of species are given and seven species are described and figured. One of these species, *Streptelasma haysii* (Meek), is a coral previously reported only from Cape Frazier above 80 degrees north latitude. A second coral, *Lindströmia solearis* n.s., is closely related to an undescribed form occurring in the Richmond rocks of northern and western localities. Four new varieties of common Ohio valley Richmond brachiopods are described; also a new pelecypod close to but not identical with a species occurring in the Ohio valley Richmond.

It is believed that the basal Depauperate fauna invaded the Mississippi valley area from the south. This zone pinches out in Minnesota but east of there it extends as far north as the Upper

Peninsula of Michigan. To the south it is typically represented at the base of the Cason shale of Arkansas. The shales immediately overlying the Depauperate zone extend even farther south as a part of the Sylvan shale of Oklahoma.

All higher faunas are believed to have invaded this region from the north. This belief is supported by their distribution (they are not found in the southern portions of the Maquoketa basin) and by the occurrence of many northern corals, echinoderms and cephalopods. It is believed that the Mississippi valley and Ohio valley areas were separated by a barrier during Maquoketa time. Careful studies show that many of the Ohio valley species heretofore identified with species occurring in the Maquoketa are not identical with those of the Maquoketa. Differences of at least varietal rank have been found in most cases.

Introduction

Purpose of the Investigation.—The Maquoketa shale was made the subject of the present investigation for two reasons—(1) because the range of its lithology and its obscure stratigraphic relations have been interpreted in so many different ways that the literature is in great confusion, and (2) because the fossils which have been reported from the formation are abundant and of a highly interesting character. It was, therefore, with the purpose of working out a series of persistent faunal zones and thereby correlating its varying lithologic and paleontologic units that the study was undertaken. The problem proves to be much larger than was anticipated and though the study is nearing completion it may be some time before all the descriptions of fossils are ready for publication. It seems advisable, therefore, to issue the report in two parts. Part I has to do primarily with the stratigraphy, though several of the more significant fossils are described. Part II will appear at an early date and will consist almost entirely of descriptions of fossils. The bryozoa will be described by W. H. Shideler, the cephalopods by Aug. F. Foerste, and the other groups by the author.

Location and Area.—As may be seen on the geologic maps published by the Iowa Geological Survey or by reference to Plate XVI the Maquoketa shale outcrops in an irregular belt extending in a general northwest-southeast direction across the northeast corner of the state. This belt is quite narrow at the southeast end but widens to about twenty-five miles in Winneshiek and Fayette counties and from there is progressively narrower to the northwest. The belt thus described begins in Howard county on the north, passes through Winneshiek, Fayette, Clayton, Dubuque, Jackson and Clinton counties, small outcrops being found also in Delaware and Allamakee counties. The total area of the belt is approximately 700 square miles.

Previous Investigations.—The Maquoketa shale has in reality claimed more than its share of attention from geologists since the days of the earliest investigators down to the present time. The literature on the formation is voluminous and no attempt will be made at this point to discuss or even to enumerate all the various articles and papers which deal with it. Mention must be made, however, of the county reports published by the Iowa Geological Survey. These reports, to which reference will be made at many places in the text, constitute the most complete, and on the whole the most reliable works available on the geology of the area under consideration. Of the nine counties making up the area Calvin(9, 11, 12, 13, 14)* has written reports on four and part of a fifth, Savage(96, 97) two, Leonard(69) one, and Udden(124) one. Other works used in the preparation of this report are acknowledged individually in the text. For a complete list of publications referring to the Maquoketa see bibliography on pages 412-417.

Field Work.—Much of the work was necessarily of the nature of reconnaissance since the area studied covers a considerable part of the northeastern corner of the state and since in large part this area has not been mapped topographically. The geologic maps available, while showing the general structure well, are in many cases inaccurate in detail. Parts of three seasons were spent in northeast Iowa and in addition short trips were made to Jo Daviess and Calhoun counties in Illinois, Pike and Ste. Genevieve counties in Missouri, to southeastern Indiana, southwestern Ohio, northern Michigan, and Ontario, Canada, to study either the Maquoketa or its possible equivalents in these places.

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* The figures in parentheses in the text refer to the publications included in the bibliography at the end of this paper.

Acknowledgments.—The writer takes pleasure in acknowledging his indebtedness to Doctor A. O. Thomas for general supervision over the work, both in the field and in the office. For parts of two summers the writer was ably assisted in the field by Mr. Homer J. Tysor.

Doctors R. S. Bassler and E. O. Ulrich kindly permitted the writer to study the large collections of Maquoketa fossils in the possession of the United States National Museum and aided him greatly in many ways, particularly in making determinations of the fossils. Many of the photographs were taken by Doctor Bassler and skillfully retouched by Miss Frances Wieser. Sincere thanks are also due Doctor Aug. F. Foerste and Doctor W. H. Shideler for valuable suggestions and encouragement. The former is responsible for all determinations of cephalopods in the present paper while Doctor Shideler has identified the bryozoa. Doctor Arthur Kyle Davis, Jr., has kindly read portions of the manuscript.

To all others who aided directly or indirectly in the carrying on of the work the writer desires to express his most cordial thanks.

Physiography

Relief.—The area in which the Maquoketa shale outcrops, lying as it does in the northeastern corner of the state of Iowa, exhibits quite a variety of topographic types. The extreme northeastern part of the state lies in the so-called Driftless Area,* where relief is notably high when compared with the deeply drift-covered areas adjoining it. Thus an area including most of Allamakee county as well as the northeast parts of Winneshiek, Clayton and Dubuque counties shows a type of topography decidedly different from that shown by any other part of the area under consideration; indeed, different from that shown by any other part of the state of Iowa. The topography is essentially that developed by running water; it is a remnant of the type of topography that existed everywhere throughout the upper Mississippi basin prior to the advance of the glaciers in the recent geologic past. It is a mature topography showing a well developed dendritic drainage pattern. Hills and ridges are high and round-backed, valleys are deep and in many places show

* This area in Iowa seems to have been glaciated though most of it is literally "driftless".

steep rocky walls. The differential resistance of the rock formations in which the topography is carved shows itself strongly in the resulting topographic forms.

The three rock formations widely exposed in the area under consideration are the Galena limestone and dolomite, the Maquoketa shale and the Hopkinton dolomite, the first named being the lowest formation. While none of the three is notably resistant to erosion the Maquoketa is much less so than the other two. Rain wash and slumping quickly level any exposure of this rock and only where conditions permit unusually rapid corrasion may a stream maintain an exposure of Maquoketa in its bed and in the sides of its channel. The Maquoketa, therefore, usually

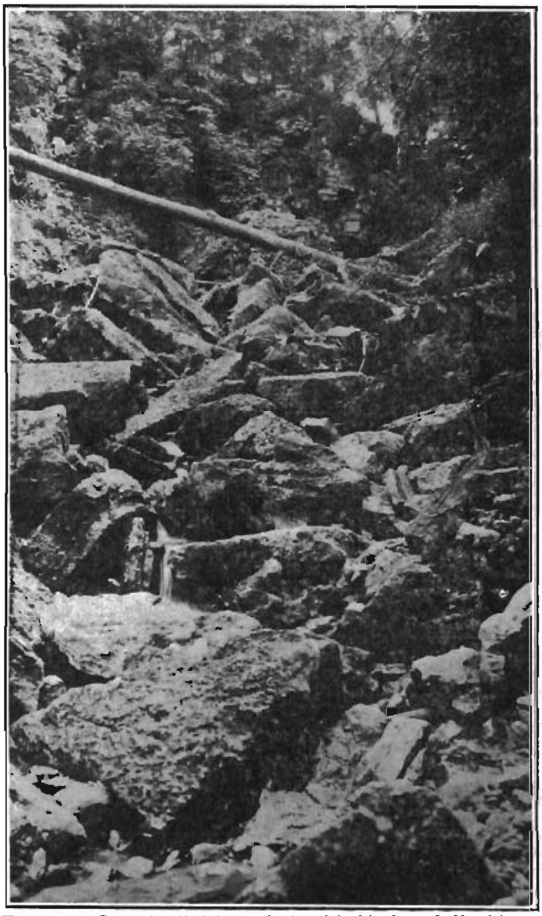

FIG. 64.—Cascade Gulch choked with blocks of Hopkinton dolomite. Southwest quarter, section 17, Dover township, Fayette county, Iowa. Photo by Thomas.

expresses itself in low rounded hills, flattened terraces and gentle slopes. Over these soft and unstable slopes great blocks of Hopkinton dolomite freed from the scarps above slowly creep to their final resting places on the underlying dolomite. Such great blocks in all stages of their journey dot the hillsides and choke up the gullies everywhere.

This sequence of rock formations of differing resistance to erosion also gives rise to rather unusual conditions where the valleys cross the strike of the rocks. If the mouth of such a valley is found well down in the Galena one notices, as he ascends, the steepness of the immediate valley walls. Many of these valleys are gorgelike in their lower reaches, showing sheer cliffs of Galena many feet in height on one or both sides. As one continues to ascend the valley floor the height of the cliffs is progressively less until, where the top of the Galena is reached, the valley widens abruptly, and the walls stretch out on both sides as gentle slopes, dotted here and there by creeping limestone blocks from the wooded Niagaran hills above. Beyond here one passes over the entire thickness of the Maquoketa and again the gently sloping valley walls give way to sharply rising bluffs. Finally gorge conditions may again be encountered but this time it is the Niagaran and not the Galena that forms the wall rock.

The Driftless Area has had an exceedingly interesting erosion-

FIG. 65.—Typical Maquoketa topography on the border of the Driftless Area west of Preston, Jackson county, Iowa.

al history for which the reader is referred to Trowbridge's paper on the subject.[121]

Lying in general to the southwest of the Driftless Area discussed above and grading gradually into it (for the depositional effects of glaciation do not end abruptly) lies what has frequently been called the Loess-Kansan Area. This area, in common with much of the state of Iowa, still shows a much dissected drift sheet. It is called the Loess-Kansan Area because the underlying Kansan drift is mantled with younger loess in most places. The drift, however, is patchy and thin, being best developed on the uplands and entirely removed in the main stream valleys, if, indeed, it ever was deposited there. In many places this drift is covered by a mantle of younger loess, but this also is thin so that, while the evidence of glaciation is clear, the old mantled pre-Pleistocene topography is recognizable. Some of the older investigators have stated that its preservation is due largely to the thinness of the border ice of the Kansan and its inability to carry much detritus. Recent work has led others to believe that the Kansan glacier carried much detritus which has since been removed from the main valleys. Like the so-called Driftless Area proper the Loess-Kansan Area shows a mature topography, fashioned chiefly by running water into a complex pattern of hills and valleys that give excellent drainage and comparatively high relief.

Lying still farther to the southwest and separated from the Loess-Kansan Area by a winding but ordinarily very distinct boundary lies the Iowan Drift Area, topographically distinct and in many ways unusual. The work of the lobate Iowan glacier in the area was largely depositional. It filled the depressions in the old erosional surface over which it advanced and when it retreated left a remarkably level plain. Its flat stretches show no sharp irregularities, only occasional gently swelling elevations not worthy of the term "hill" and equally undefined depressions which, unless artificially drained, give rise to shallow marshes and sloughs. It is doubtful if the ancient topography plays a very important part today in determining the drainage, though perhaps some of the better defined sloughs represent the incompletely filled main valleys of the old surface. This boulder-strewn plain is still in earliest youth. Sufficient time has not elapsed to allow modern streams to deepen their valleys to any appreciable extent. In many places a series of hills and ridges borders the Iowan plain and separates its many lobes from the mature Kansan topography. Some of these elevations are composed almost entirely of loess while others have a core of drift. Their origin is still somewhat problematical and it need not be discussed here.

In addition to the three main topographic areas described above there are also many topographic features which are of minor importance but nevertheless are of much interest. Among these are to be listed abandoned river valleys like Couler Valley and Goose Lake Channel. Regarding these the reader is referred to the writings of McGee and others.

Drainage.—The drainage is in large part controlled by Mississippi river, which bounds Iowa on the east. A number of important tributaries to the stream flow in a general northwest-southeast direction and tend to follow the strike of the outcropping formations. Named in order from north to south the more important of these streams are Upper Iowa (Oneota), Yellow, Turkey, Little Maquoketa, Maquoketa and Wapsipinicon rivers.

FIG. 66.—Lowlands of old Goose Lake channel as seen from the west bank. Fairfield township, Jackson county, Iowa.

Most of these streams have their headwaters in the poorly drained reaches of the Iowan plain and thence flow in shallow sloughs to the Loess-Kansan Area, where valleys are better developed, and on to the Driftless area, where without exception all occupy what appear to be pre-Kansan valleys deeply cut into the underlying rocks. The main facts concerning the drainage are thus simply told but, as previously suggested, the detailed history of many of the streams is exceedingly complex, stream piracy, diastrophism and several epochs of glaciation all having played important parts.

Stratigraphy

General Statement.—As will be observed in the table which follows, the Maquoketa shale, in the state of Iowa, comes into contact at various places with a number of distinct geological formations of Paleozoic age. With most of these it seems distinctly unconformable.

It is underlain by the "Dubuque formation" of Sardeson, which many workers regard as a portion of the Galena formation. Here the results of many investigations seem to prove conclusively that no distinct *erosional* unconformity exists though there is much evidence of other sorts to indicate that a considerable time may have elapsed between the deposition of these two formations.

Three Silurian formations overlie the Maquoketa and each may be seen in direct contact with it at various points. The older two of these three, the Edgewood and Kankakee limestones, have been referred by Savage to the Alexandrian series of the Silurion.[100, 103] The third, the most extensive of the three, has long been called the Hopkinton dolomite and referred to the Niagaran series of the Silurian. With all three of these Silurian formations the Maquoketa shale is unconformable.

In the northern part of the Maquoketa belt in Iowa the Silurian disappears and the Wapsipinicon formation, of Upper Devonian age, may be seen in contact with the Maquoketa.

In the southeast corner of Jackson county and the adjoining portion of Clinton county to the south, a small inlier of Maquoketa shale occurs. Apparently its presence is due largely to arching and subsequent erosion in post-Niagaran, pre-Pennsylvanian time. Thus the Des Moines sandstones, of Lower Pennsylvanian age, are seen resting directly upon the upper portion of the Maquoketa shale at this locality.

Legend.—The following table includes all the formations that may be seen in contact with the Maquoketa shale in Iowa.

GROUP	SYSTEM	SERIES	FORMATION
Paleozoic	Pennsylvanian	Lower Pennsylvanian	Des Moines
	Devonian	Upper Devonian	Wapsipinicon
	Silurian	Niagaran	Hopkinton
		Alexandrian	Kankakee Edgewood
	Ordovician	Cincinnatian (Richmond)	Maquoketa
			Dubuque
		Mohawkian	Galena

HISTORICAL SKETCH

In the introduction reference was made to the extreme variability of the Maquoketa and to the resulting diversity of interpretation. A brief historical sketch will serve to bring out the latter fact more clearly. Although the writer has consulted all available references dealing with the formation no attempt will be made here to mention all of them. For a fairly complete resumé of the literature prior to 1890 the reader is referred to James' paper on the subject.(52) A few years later, in 1895, Winchell and Ulrich included an "Historical sketch of investigation of the Lower Silurian in the Upper Mississippi Valley" in Vol. 3, pt. 1, of the final report on the Geology of Minnesota. The writer found this a very valuable guide. Contributions since these dates seem to be in more general agreement though the questions of the age and correlation of the formation are by no means settled.

As far as the writer has been able to discover the first reference to the rock now known as the Maquoketa shales was made in 1840 by John Locke in his report to David Dale Owen then "Principal Agent to explore the Mineral Lands of the United States". Locke gives a geological section from the South Fork of Little Maquoketa through Dubuque to Sinsinewa Mound, Wisconsin, in which the rocks now called Maquoketa are grouped with the underlying Galena to form the lower portion of the "Cliff limestone". Referring to the lead-bearing rocks at Dubuque, now recognized as the Galena formation, he mentions the "cap-rock, thin layers of shale".(70) These evidently belong to what we now know as Maquoketa for the basal layers of that formation do occur above the lead-bearing beds at Dubuque.

In 1842 Hall (40) wrote a report of an extended trip through the middle west taken in 1841. He did not differentiate the two dolomite formations now known as Galena and Niagaran (Hopkinton) which lie below and above the Maquoketa in Iowa and adjoining areas.

In the year 1851 a report by Foster and Whitney was published,(32) in which they recognized the existence of the Galena limestone as a separate formation, placing it between the "Trenton Group" and the "Hudson-river Group" as these are developed in New York. Regarding the Ohio-Iowa-Wisconsin equivalent of the last named group they say (p. 5) "associated with No. 3 or the Blue Limestone and Marls of Ohio". Since in their own table these "Blue Limestones and Marls" are made Trenton in age they really make the western Maquoketa also Trenton in age, disagreeing with Hall, who in the same volume states (p. 296) "........ the blue limestone, as it appears at Cincinnati, is only the Hudson-river Group; and that the Trenton and other limestones, or their equivalent, lie below it".

In this same volume Hall describes the "Hudson-river Group" as it is developed in the Upper Peninsula of Michigan. If the correlation recently advanced by Hussey(50) and followed in the present paper be correct and if the lower Richmond rocks of that area really are referable to the Maquoketa, then Hall's observations constitute the first serious attempt to describe the present Maquoketa formation. Hall himself, recognizing that the "Hudson-river" capped rocks that resembled the Galena ("upper ash colored beds on the Escanaba") and knowing that the Galena existed in Wisconsin and Iowa, believed that the shales were found there also. His chief evidence was the basal zone of small molluscs found by him in the Little Bay de Noquette area. Others had reported similar fossiliferous material from the glacial drift and some one had sent him a specimen from Galena, Illinois, said to have been obtained in place (pp. 148-151).

Owen's survey[84] in 1852 failed to recognize the "Hudson-river Group" in its true position in the lead region though the name is given in its proper place (grouped with the Trenton) in the legend of the areal map.

In 1854 Edward Daniels, then State Geologist of Wisconsin, published a "First Annual Report",[24] which dealt mainly with the economic resources of the lead region. In the section given the "Nucula Shale" (basal Maquoketa) is placed correctly between the lead-bearing "Gray Limestone" (Galena) and the "Coralline Beds of Dr. Owen" (Niagaran). His observations on the "Nucula Shale" and its fossils (he speaks of the assemblage as a "fossil Lilliput") are very interesting.

One year later James G. Percival wrote a report similar to the one quoted above.[85] He speaks of Daniels' "Nucula Shale" as the "Blue Shale", places it in its true stratigraphic position in that area and mentions its fossils but does not mention its possible correlation with the "Hudson-river Group" of New York as Hall had suggested in 1851. In Percival's second report, published shortly after his death the following year, he cited the occurrence of the "Blue Shale" in the eastern part of Wisconsin along the eastern shore of Green Bay. He found no evidence of Daniels' "Nucula Shale" at the base of the shale but instead "a third bed of fossiliferous limestone" abounding in "shells of the genus *Leptaena,* and in some of its layers is (are) round and flattened branched corals. . . . ." These latter he also reported from the shale of the west and looked upon them as a "connecting link".[86]

This is not the first published correlation of the shale of the lead region with the Hudson River rocks of the east shore of Green Bay as stated by Winchell and Ulrich (164, p. xxviii), for Hall, as shown above, had made this suggestion five years before.

Hall was the first worker to describe the Iowa occurrences of the formation. This he did at some length in 1858 under the name "Hudson River Group".*

In the same year appeared another Wisconsin Annual Report by Daniels, most of which has to do with the "Iron Ores of Wisconsin". He recalls his discovery of the "Blue Shale" in 1851,

* Hall, James, Geol. Survey of the State of Iowa, pp. 64-71, 1858. In this same volume, on page 314, Whitney erroneously correlated the limy Fort Atkinson member of the Maquoketa in Winneshiek county with the Galena limestone. Calvin made the same error but corrected it later. See page 332 of this paper.

described by him two years later as the "Nucula Shale". He states that Hall recognized it in Foster and Whitney's Report on the Lake Superior Land District "as belonging to the Hudson River Group".[25] For this Winchell and Ulrich (164, p. xxx) hold him in error, but as previously mentioned Hall did suggest this correlation. In fact Hall himself called attention to his first observations some years after they were made. He said:

"In Foster and Whitney's 'Report upon the Lake Superior Land District', I have shown, as I think very clearly, the relation of the Hudson River Group of New York with the calcareous shales with limestone bands, on Little Bay de Noquet and the peninsula between Little and Big Bay de Noquet; and also the occurrence of the same beds on the east side of Green Bay: and I have also shown the relation of these rocks with those of the southwestern localities".[48]

In 1861 Hall described a number of fossils some of which were from the Maquoketa of Iowa.[44]

Several years later Hall and Whitney[48a] described the same rocks as they occurred in Wisconsin under the name "Green and Blue shales and limestone". Hall rejected the term "Hudson River Group" and correlated the beds with the Blue limestone of Ohio, with the Utica and Frankfort slates, and with the Pulaski shales and sandstones and the Lorraine shales of New York. All these last named formations had also been erroneously included in the original Hudson River Group. Strangely enough, Whitney in a later section of the same volume, page 177, also discusses these rocks but retains the name Hudson River Group.

Meek and Worthen were the first authors to adopt the existing correlation and to state that the shales overlying the Galena in the Upper Mississippi basin were the western equivalent of the Cincinnati series of the Ohio-Indiana region.[74] The following year Worthen and also Whitney, in discussing the geology of Illinois, used this correlation.[166] In 1868 Meek and Worthen published a description of a number of Hudson River fossils from Illinois.[76]

The actual term "Maquoketa shales" was first applied in 1870 by White, who, in defining the formation, states:

"*Area and General Characters*: The surface occupied by this formation is comprised within a singularly long and narrow area, seldom reaching more than a mile or two in width, but more than a hundred miles long within the State. It lies like a narrow sinuous band upon the surface between the regions occupied respectively by the Galena and Niagara limestones; having, like them, a northwestward and southeastward trend. Its most southerly exposure is in the bluffs of the Mississippi river near Bellevue, in Jackson county, and the most northerly one yet recognized is in the western part of Winneshiek county.

"The whole formation is largely composed of bluish and brownish shales which weather into a tenacious clay upon the surface, and the soil derived from it is usually stiff and clayey. The shales are sometimes slightly arenaceous, and sometimes calcareous bands compose a considerable part of its bulk. The latter is the case at the typical localities on the Little Maquoketa river about twelve miles westward from Dubuque.

"*Geological Age*: The fossils contained in this formation, together with its position in relation to the underlying and overlying formations, leave no doubt as to the propriety of referring it to the same geological period as that in which the rocks at Cincinnati, Ohio, were formed; but as a formation, it is regarded as distinct from any other one of the group hitherto defined. In the former report upon the geology of Iowa, it received the name of Hudson River Group, in consequence of its supposed equivalency to certain rocks abundantly exposed along the Hudson river in New York. But the designation 'group' refers to a whole period in geologic time, and when it is applied to any single formation, its indefiniteness differs only in degree from a mere reference of the formation to its proper system or age. Therefore, as the strata of this formation, all referable without doubt to a single epoch of its period, are well developed on the Little Maquoketa river, where its characteristic fossils are also abundant, the name Maquoketa shales is given to this particular formation of the group."[(148)]

Having thus described the formation, White agrees with Meek and Worthen in their adoption of the term "Cincinnati Group" to replace the "Hudson River Group", formerly applied to Iowa and Illinois rocks and states again his desire to "use the name Maquoketa shales to designate that particular epochal subdivision or formation of the group which alone is found in Iowa."[(148)]

The fourth Report of the Illinois Survey was issued in the same year that White defined the Maquoketa of Iowa. In this volume F. H. Bradley discusses the rocks of the "Cincinnati Group" as exposed in Grundy, Will and Kankakee counties.[(5)]

In 1872 Shaw mentioned briefly the Cincinnati group as developed in northwestern Illinois. The same volume contains his report on Jo Daviess county in which the rocks are treated in more detail.[112] The variation in total thickness is mentioned.

In 1873 Rominger described the "Hudson River or Cincinnati Group" of Michigan, giving faunal lists. Regarding the basal shales exposed at Bill's creek in the Bay de Noquette district he stated:

"The similarity of these beds with the shales representing the Hudson river group in the lead regions of Illinois and Iowa is very obvious, and the differences existing between them and the more eastern strata would find their explanation in the somewhat older date of the western, prevalently shaly deposits."[89]

In 1876 N. H. Winchell,[159] in describing the rocks of Fillmore county, Minnesota, accepts White's name Maquoketa for the Cincinnatian rocks said to occur two miles south of the Minnesota line but not actually observed in that state.

Essentially the same report was again published in 1884. In one place at least the author seems to have included part of the lower Maquoketa with the Galena[161] as pointed out by Sardeson in 1896.[93]

In 1877 a number of Hudson River fossils were described by R. P. Whitfield[149] and were republished in 1882.[151]

During the years from 1878 to 1890 a number of other articles appeared, dealing with the Maquoketa and the rocks then assigned to the Maquoketa. For a complete list the reader is referred to Winchell and Ulrich's Historical Sketch previously mentioned and to the bibliography of the present paper.

Finally, in 1890, J. F. James published an article entitled "On the Maquoketa shales, and their correlation with the Cincinnati Group of southwestern Ohio".[52] As previously stated, James' paper gives a fairly complete resumé of the history of the formation prior to 1890. In addition to this he gives the results of his own observation and summarizes with the statement on page 356 "...... that the Maquoketa shales are the almost direct continuation of the Cincinnati series, that the paleontologic features of the two are the same, and that the position of the two in the geological scale is the same, it does not seem wise to retain the name Maquoketa as a distinct formation. It would seem better to consider the rocks as part of the Cincinnati series, dropping the term Maquoketa altogether". However, it is now generally believed that James' interpretations are open to criticism and his conclusions have not been accepted.

In 1891 McGee discussed the Iowa Maquoketa briefly, summarizing the characteristics of the formation and upholding White's definition.[71] He, however, misinterpreted the cherty dolomite of what is now known as the Fort Atkinson member of the Maquoketa, correlating these rocks with the lithologically similar Niagaran rocks of adjoining areas.

The next extended discussion of the formation appeared in the form of a series of articles by F. W. Sardeson entitled "The Galena and Maquoketa Series".[93]

In Part I of that series the author defines his terms, states some of the problems involved in a study of the series and gives a summary of classification by all authors. (The references here were of great help in preparing the present sketch.) Part II gives the author's subdivision of the series and describes the fauna of each member, including their relations to each other. Parts III and IV of the same series are devoted chiefly to a discussion of the paleontological evidence upon which the classification previously advanced is founded. Sardeson followed these papers almost immediately by another in which he discusses all available nomenclature dealing with the Galena and Maquoketa series.[94]

In 1902 Ulrich and Schuchert[141] called attention to the great importance of the Richmond submergence in the geological history of North America. They stated that probably the entire Mississippian sea of that time was in open communication with Anticosti and northern Europe.

Some years later Foerste[27] reported upon the Brachiopods of the Richmond group and stated that the Richmond basin of the Ohio valley probably was connected with that of the Mississippi valley by way of northern Indiana and Illinois.

In 1911 Ulrich published his masterly "Revision of the Paleozoic Systems"[131] in which certain of the problems of the Maquoketa are carefully discussed. He mentions the Utican aspect of the Maquoketa fauna and the fauna of the Sylvan shale of Oklahoma (a southward extension of the Maquoketa of Iowa) but points out the fact that whereas the last mentioned two formations overlie unquestioned Richmond faunas, the Utica lies just above the Trenton at the base of the Cincinnati series. He expresses the opinion that the Maquoketa did not originally extend over all the known areas of the Fernvale limestone, a formation that occurs beneath it in numerous places in eastern Missouri and southern Illinois. The beds of this southward extension of the Maquoketa are said to be in every way typical of the Iowa formation save that they are thinner. Evidence is advanced which suggests that the Maquoketa waters may have invaded from the north and east.

Two years later an important paper by the same author appeared, in which the question of the Ordovician-Silurian boundary is carefully and fully discussed. The Maquoketa and its fossils are mentioned in several connections and a map of North America, showing composite Richmond seas, is given.(132)

A number of new trilobites from the Maquoketa of Fayette county, Iowa, were described by Slocom in 1913,(113) and these descriptions were republished with a few changes and additions by the Iowa Survey three years later.(114)

Savage and Van Tuyl, in 1919, wrote concerning the "Geology and Stratigraphy of the Area of Paleozoic Rocks in the Vicinity of Hudson and James Bays".(105) The Shammattawa limestone of the Cincinnatian series is correlated with the upper Ordovician (Stony Mountain) limestone in the vicinity of Lake Winnipeg, with the Fish Haven dolomite of Utah, the Big Horn dolomite of Wyoming, and the upper and middle parts of the Fremont limestone of Colorado. These rocks are believed by Savage and Van Tuyl to be equivalent in time to some part of the Richmond and Maquoketa of the Ohio and Mississippi valleys but "quite different" since the former were deposited in a basin which connected with the Arctic while the Maquoketa and Ohio valley Richmond are thought to have had a southern or eastern origin. On one of the maps accompanying the report the Mississippi valley area is separated from areas to the north and west.

A number of new echinoderms from the Maquoketa were described in 1924 by Slocom and Foerste.(115) The latter states that the general distribution of such forms as *Pleurocystites*, *Poro-*

crinus, Peritocrinus and *Carabocrinus* "suggests that they belong to a northern circumpolar fauna, known in North America during early Trenton times, especially during Curdsville times, and the recurrence of these genera in the Lower Maquoketa of Iowa suggests that here also we have a northern invasion" (p. 358).

In the same year Foerste published his "Upper Ordovician Faunas of Ontario and Quebec".(31) Richmond faunas, their origin and probable routes of migration are discussed at some length. The author believes that many species from different provinces heretofore recognized as identical will prove to be distinct. Thus he states that *Dinorthis subquadrata* from the arctic invasion is not identical with *D. subquadrata* from the Cincinnati area and *Hebertella insculpta* from the Maquoketa is not identical with *H. insculpta* from the Blanchester of Ohio and Indiana (p. 23).

Savage in 1924 discussed the "Richmond Rocks of Iowa and Illinois"(102) and attempted correlations which the present writer believes are in error. See page 368 of present paper.

The importance of the break between the Richmond and the underlying rocks in the upper Mississippi Valley was briefly mentioned by Ulrich in 1924.(136)

Accompanying the Annual Reports of the Iowa Geological Survey for 1923 and 1924, which appeared in 1926 as volume XXXI,(146) is a paper by Walter on the trilobites of Iowa. A number of Maquoketa forms are described and figured.

Ulrich's latest attempt to settle the Ordovician-Silurian Boundary controversy appeared in 1926.(138) The Maquoketa and other Richmond rocks of the Upper Mississippi valley are mentioned in a number of places. Of particular interest is the statement that in the Mississippi valley the differing sequence of Richmond deposits suggests "a number of probably short interruptions of sedimentation, and some of these were accompanied by land surface tilting and consequent great changes in the direction from which the seas and faunas invaded the continental basins" (p. 327).

In the same year R. C. Hussey published a paper describing the stratigraphy and paleontology of the Richmond formation of Michigan.(50) A part of the Michigan Richmond is correlated with the Maquoketa of Iowa. See pages 362 to 367 of the present paper.

Considering the amount of published material which has appeared on the Maquoketa the foregoing account is sketchy in the extreme. It does not aim at completeness but rather to give the reader some true idea of how much has been written and how widely opinions have varied.

DISTRIBUTION

The general known distribution of the Maquoketa shale is shown on Plate XV. In Iowa the Maquoketa outcrops are confined almost entirely to an irregular northwest-southeast belt running across the northeast corner of the state. To the northwest this belt continues into the state of Minnesota while to the southeast it is well developed in adjoining districts in Illinois and Wisconsin. In Iowa, as previously mentioned, the belt of outcrops crosses the following counties: Howard, Winneshiek, Allamakee, Fayette, Clayton, Delaware, Dubuque, Jackson, and Clinton. The belt ranges in width up to twenty-five miles, the average width being approximately five miles. (See Plate XVI.)

The explanation of this linear outcrop lies chiefly in the gentle regional dip to the southwest which brings the basal beds and the underlying dolomite to the surface in the northeast and causes the uppermost Maquoketa beds to disappear under the Silurian and other younger rocks to the southwest. This dip also makes the Maquoketa outcrops extend progressively farther upstream in the beds of the northern east-flowing streams. The southernmost exposure of the Iowa Maquoketa is found in Spring Valley township in Clinton county, the northernmost in Howard county at the Minnesota line. As mapped by the Iowa Geological Survey the belt is much generalized, especially in the north. This is due chiefly to the great amount of drift.

Aside from the irregular northwest-southeast belt just described the only outcrop of the Maquoketa shale is a single inlier. This inlier spreads over portions of Fairfield and Van Buren townships in Jackson county and extends into Clinton county, where it is limited to old Goose Lake channel and the valley of the present Sugar creek.[63]

CHARACTERISTICS

In 1870 when White named the formation in Iowa he called it the Maquoketa shales. Since that time other workers, who have recognized the formation in areas adjoining the type locality, have discovered that the rock is not all shale and have therefore questioned the appropriateness of the name given by White. It is true that locally the formation contains large amounts of limestone, dolomite and chert, but the fact remains that at its type locality it is practically *all shale* and that everywhere it contains a *large amount* of shale. Hence, in this report, general custom and field evidence are followed and the formation is spoken of as the Maquoketa shale.

On the basis of lithologic differences, with which are associated faunal differences, the belt in which the Maquoketa shale outcrops in Iowa may be divided into two parts, the line of separation being shown on Plate XVI. These two areas of outcrop may be spoken of as the *Northwest Area* and the *Southeast Area,* the names referring to that part of the Iowa belt where the section is best developed. Thus the Northwest Area includes Howard, Winneshiek, Allamakee, Fayette and part of Clayton counties. The southeast section is best seen in part of Clayton, in Delaware, Dubuque, Jackson and Clinton counties.

Northwest Area: The Maquoketa shales in this province were separated by Calvin into the following distinct members, the type sections of which are located in northeast Fayette county and southwest Winneshiek county (13, pp. 97,98). See under "Typical localities", pages 332-339.

"4. *Brainard Shales.*—Blue and bluish-gray shale, with some intimately associated beds of limestone at the top and bottom of the division. . . It is proposed to designate this member by the name of the small railway station in Fayette county near to which it has its most typical development. Thickness about 120 feet.

"3. *Fort Atkinson Limestone.*—Massive, yellow, cherty, dolomite and associated beds of limestone. . . best exposures occurring at Fort Atkinson. Thickness 40 feet.

"2. *Clermont Shale.*—Bluish colored, plastic, fine grained shale, well developed below the Fort Atkinson limestone at Clermont in Fayette county. . . Thickness 15 feet.

"1. *Elgin Shaly Limestones.*—Limestones, dolomites and shaly limestones with beds of calcareous shales and thin partings of bluish, less calcareous clays; quite variable in character and fossil contents, but generally yellowish, decidedly calcareous and more indurated than the blue, plastic shales of 2 and 4. . . Near Elgin the Isotelus beds at the base of this member are largely blue, hard, fine grained limestone. Thickness of entire member 70 feet."

Southeast Area: This province includes the exposures along Little Maquoketa river, in Dubuque county, designated by White the type exposures of the Maquoketa. In some respects White's choice was an unfortunate one for some of the outcrops which he studied are extraordinary in many ways and are duplicated nowhere else. The section shows very unusual lithologic characters and bears many unique fossiliferous beds. It may be added also that only the lower part of the formation is well exposed. However, this Little Maquoketa valley exposes the type section, which shows what is after all the chief characteristic of the southeast phase—namely an almost total absence of indurated rocks. Aside from a few feet of thin limestone layers near the top and an even thinner zone of indurated beds at the base the Maquoketa in this province is made up of green or blue shale throughout. In section 29, township 86 north, range 5 east, practically the entire thickness of 190 feet is exposed.

Columnar Sections:

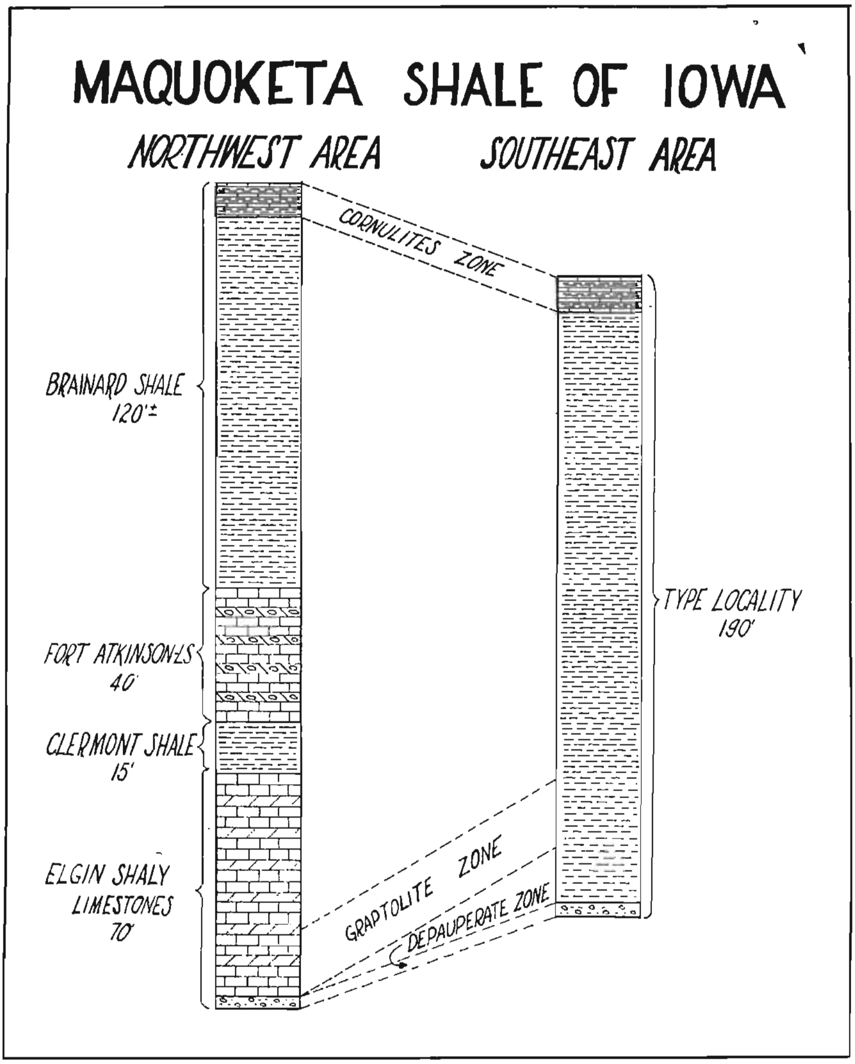

FIG. 67.—Columnar sections of the Maquoketa in the Northwest and Southeast Areas in Iowa.

TYPICAL LOCALITIES

Numerous and very satisfactory descriptions of outcrops of the various horizons of the Maquoketa shale have been given by the authors of the county reports. It is not the purpose of the present paper to review the work of these men nor to repeat their observations except in so far as they require brief comment or modification. In a number of cases outcrops have been changed considerably by the passage of two decades of time, some for the better and others for the worse. On many occasions during the present investigation the writer found grassy slopes or talus heaps where previous workers had reported good detailed sections or he found unusually good collecting where others had found little or nothing. Thus, for example, of the six members of the "Dover Mills section" so carefully described by Savage in his Fayette county report only three can now be seen satisfactorily, whereas in the Clermont shale pit where Savage reported fossils to be somewhat rare the writer found weathered shale slopes which yielded the best fauna collected from this member at any single locality. In many other cases the recent cuts on the primary roads gave sections and fossil collections not available in earlier days. A notable example of this is seen in Allamakee county where excellent exposures of lower Maquoketa beds are found along at least four different roads leading north and east of Postville, giving some ten square miles of Maquoketa in this county, yet in 1895 no shales were found and the southeast corner of the county then was mapped as Galena.*

In the pages which follow, the horizons of the Maquoketa are taken up in order and the best exposure of each is briefly described, followed by a list of other good localities where the same strata may be seen. The writer visited these places during his investigation. For additional remarks on certain ones and for others not here included see the various county reports on the area.

Northwest Area

Savage's "General Section" of the Maquoketa as developed in Fayette county is quoted below. It seems applicable to the entire Northwest Area. The names of the members have been added to the section as originally published by Savage (93, pp. 484-486).

"General Section of the Maquoketa Shales

	FEET
Brainard member	
13. Bed composed of bands of soft, bluish-gray shale, two to four inches in thickness, which alternate with thin layers of limestone one to three inches in thickness, having a band of reddish shale two feet in thickness at the base. These materials are fossiliferous throughout†	8–12

* Calvin interpreted the exposed beds of the Fort Atkinson member as Galena dolomite. Iowa Geol. Survey, IV, p. 80; 1895. Later he called attention to his own error. Iowa Geol. Survey, XVI, p. 106; 1906.

† Lists of fossils omitted here and elsewhere.

12.	Bed of blue colored, plastic shale, without distinct planes of bedding; containing small concretions of iron pyrites in the upper part and numerous large crystals of selenite below; bearing no fossils	95–100
11.	Transition beds from the Middle to the Upper Maquoketa; consisting of layers of yellowish arenaceo-magnesian limestone, three to eight inches in thickness, alternating with bands of dry, indurated, impure shale; without fossils	3–5
Fort Atkinson member		
10.	Massive bed of yellow colored limestone, which in some places is dolomitic, sometimes showing indistinct planes of bedding that separate the ledge into perfect layers, six to twelve inches in thickness; bearing few fossils, and occasional concretions of chert	5
9.	Bed of impure limestone (in some places dolomitic) made up of quite regular layers, two to six inches in thickness; containing a large quantity of chert in the form of nodules and imperfect bands; bearing fossils	12–14
8.	Bed of fine-grained, impure limestone, in even layers six to ten inches in thickness, consisting largely of chert nodules imbedded in the layers or of chert bands segregated along the planes of bedding; containing large individuals of several types of brachiopods	18–21
7.	Massive bed of yellow colored, fine-grained dolomite, which in some places is divided into thin layers; containing a number of chert nodules	5–7
Clermont member		
6.	Bed of bluish colored, plastic, rather fine-grained shale; in places containing numerous fossils	10–14
Elgin member		
5.	Bed of lean, yellowish-gray shale, in places somewhat arenaceous; containing, in the lower part, thin bands of impure limestone, three to six inches in thickness	10–13
4.	Bed composed of layers of yellowish-gray shale, three to six inches in thickness, separated by bands of impure limestone about equal in thickness to the seams of shale, becoming more calcareous below; bearing numerous nodules of chert	14–16
3.	*Nileus vigilans* zone: consisting of a bed of gray colored limestone in layers one to four inches in thickness, which are separated from one another by thin bands of gray shale	13–16
2.	Bed of bluish or yellowish colored shale, usually dry and indurated, in layers two or three inches in thickness, between which thin bands of limestone or irregular seams of chert nodules are intercalated	15–18
1.	*Isotelus maximus* zone: composed of layers of bluish, fine-grained argillaceous limestone, four to eight inches in thickness, alternating with bands of bluish-gray shale of about the same thickness as the calcareous layers. The indurated materials break with a smooth fracture and contain very abundant fragments of the trilobite *Isotelus maximus*	14–16 "

Elgin shaly limestones (Nos. 1 to 5 of the General Section)

For a description of outcrops of the basal Depauperate zone and the shales immediately overlying it see pages 375 to 383.

*Number 1 of the General Section, Isotelus beds.**—No better locality for this horizon can be found than the well known exposure in the northwest quarter of the southeast quarter of section 19, Marion township, Clayton county, along the left bank and in the bed of a small north flowing tributary of Turkey river.

* Formerly known as the "Isotelus maximus zone". Recently Slocom, with good reason, has assigned the bulk of the *Isotelus* remains of these beds to Owen's species, *Isotelus iowensis*. See Iowa Geol. Survey, XXV, p. 195; 1916.

A short distance below the road crossing the Depauperate layers are in place over the older dolomite. Over them are four feet of dark shales, practically barren, above which the Isotelus beds proper begin. A number of feet are exposed, showing dark, fine-grained, argillaceous limestones, well bedded and weathering into lighter colored angular blocks. Fragments of *Isotelus iowensis* crowd many of the layers, which are easily split parallel to the bedding planes. Pygidia make up the bulk of the fragments but all the other parts may be found. Graptolites associated with a few other fossils are found abundantly in certain of the beds.

Other exposures of the *Isotelus* beds may be seen in the following places: (1) a short distance west of the middle of section 35, Clermont township, Fayette county (banks of the creek above the bridge); (2) Dover Mills section, east-central section 26, Dover township, Fayette county; (3) southwest quarter of the northwest quarter of section 9, Madison township, Winneshiek county, exposed for some distance along east-west road which crosses Ten Mile creek and its tributary at this point; (4) along road between the eastern halves of sections 14 and 23, Orleans township, Winneshiek county, one-eighth mile west of schoolhouse; (5) southeast quarter of section 14, Orleans township, Winneshiek county, small quarry north of road on land owned by Mr. Goocher; (6) section 20, Post township, Allamakee county, north of Postville along primary road No. 51; (7) southeast quarter of section 22, Post township, Allamakee county, several places along road; (8) Albion township, Howard county, quarry on left bank of Upper Iowa river; (9) section 9, Albion township, Howard county, right bank of Upper Iowa river; (10) Granger, Fillmore county, Minnesota, 150 yards northwest of old brewery buildings.

Number 2 of the General Section.—This series of beds is fairly well exposed as part of the Dover Mills section in the east-central part of section 26, Dover township, Fayette county. Here a thickness of 18 feet is described by Savage as follows (96, p. 466):

"Bed consisting of layers of lean, yellowish colored, indurated shale, two to three inches in thickness, with some irregular layers of limestone and bands of chert nodules of about equal thickness with the seams of shale. Fossils rare."

Beds believed to be the equivalent of the above are to be found in the following places: (1) a short distance west of the middle of section 35, Clermont township, Fayette county; (2) northeast quarter of section 34, Clermont township; (3) southwest quarter of southwest quarter of section 9, Madison township, Winneshiek county, north side of road immediately west of bridge; (4) center of section 8, Madison township, Winneshiek county; (5) along road separating the western halves of sections 5 and 8, Madison township, Winneshiek county; (6) southwest quarter of southeast quarter of section 8, Madison township, Winneshiek county; (7) southwest quarter of southeast quarter of section 7, Madison township, Winneshiek county.

*Number 3 of the General Section, Vogdesia beds.**—South of the bridge over Roger's creek at the eastern edge of the town of Fort Atkinson there is found an excellent exposure of the *Vogdesia* beds of the Elgin member. The rock is shaly limestone and outcrops along the right bank of the creek for a considerable distance. Fragments of the trilobite *Vogdesia vigilans* are extremely abundant and cephalopods are present in such numbers as to suggest the "*Orthoceras* beds" of the basal Maquoketa at Graf. Quite a variety of other fossils may be found.

Other exposures of the *Vogdesia* beds were seen at the following places in Fayette county: (1) northwest quarter of southwest quarter of section 21, and northeast quarter of southeast quarter of section 20, Clermont township; (2) Cascade Gulch, southwest quarter of section 17, Dover township; (3) northwest quarter of section 4, Dover township, bed of south flowing creek; (4) Dover Mills, east central section 26, Dover township.

Numbers 4 and 5 of the General Section, Upper Elgin beds.—A few feet of this highly fossiliferous section outcrop at two places along the east-west road in the southeast quarter of section 17, Orleans township, Winneshiek county. Collecting is excellent at these points. Most of the fossils are silicified; many are weathered free while others stand out in sharp relief on the slabs of brown argillaceous limestone. (See Plate X.)

Additional localities are as follows: (1) near the middle of the

* Until recently these were known as the "Nileus beds" but since Raymond has referred their index fossil to the genus *Vogdesia* it seems appropriate to change the name of the beds accordingly. See Raymond, P.E., Bull. Mus. Comp. Zool., Harvard, 64, No. 2, p. 292; 1920.

east side of section 19, Clermont township, Fayette county; (2) northwest quarter of the southwest quarter of section 21 and northeast quarter of the southeast quarter of section 20, Clermont township, Fayette county; (3) southeast quarter of section 25, Dover township, Fayette county, in road gutters 15 feet above an exposure of the Vogdesia beds; (4) road between sections 23 and 24, Springfield township, Winneshiek county; (5) east of the bridge over Roger's creek, south end of "10th Ave.", Fort Atkinson, Winneshiek county; (6) northeast quarter of the northeast quarter of section 28, Post township, Allamakee county.

Clermont shale (No. 6 of the General Section)

This member does not appear to be recognizable over as large an area as the other three of Calvin's subdivisions. This may be due in large part to the fact that it is composed of easily weathered shale and is a thin member. It was found exposed at comparatively few places, the shale pit at the town of Clermont yielding by far the best fossil material. This pit is located in a hillside a short distance northeast of town and was being worked at the time of the writer's visit. The fresh exposure seemed barren but weathered slopes at the sides of the pit yielded an abundance of fossils. At this locality the shale is seen to be overlain by the resistant beds of the Fort Atkinson limestone member.

The Clermont shale was recognized also at the following places: (1) Cascade Gulch in the southwest quarter of section 17, Dover township, Fayette county; (2) southeast quarter of section 26, Dover township, Fayette county, along the road; (3) southwest quarter of section 33, Military township, Winneshiek county, creek bed south of road: (4) east of the bridge over Roger's creek at the south end of "10th Ave.", Fort Atkinson, Winneshiek county; (5) southwest quarter of section 4, Washington township, Winneshiek county, along road.

Fort Atkinson limestone (Nos. 7 to 10 of the General Section)

The best exposure of this member is found at the type locality, the quarry at the old fort near the town of Fort Atkinson. Other and almost equally satisfactory exposures are to be seen in the northwest quarter of section 15, Military township, Winneshiek county. There are two small abandoned quarries, one on either side of the road, three-fourths mile southwest of Ossian. The one on the northwest is visible from the main road, the other may be quickly reached by following a secondary road leading southeast. The rock in both quarries is lithologically identical with that seen at the type locality but is more weathered. These are the localities from which specimens of the unusual coral *Lindströmia solearis* n.s. were obtained.

The beds of this member are to be seen also in the following places: (1) Cascade Gulch, southwest quarter of section 17, Dover township, Fayette county; (2) Clermont, at the shale pit a short distance northeast of the town; (3) southwest quarter of section 4, Washington township, Winneshiek county; (4) southwest quarter of section 33, Military township, Winneshiek county; (5) southeast quarter of the southeast quarter of section 1, Jackson township, Winneshiek county.

Brainard shales (Nos. 11 to 13 of the General Section)

Nos. 11 and 12 of the General Section, Barren lower portion.— Excellent exposures of this part of the Brainard member are to be found in the right bank of a small creek, tributary to Otter creek, in the southeast quarter of the northwest quarter of section 30, Pleasant Valley township, Fayette county (about one-half mile west of Brainard). At this locality there are also small outcrops along the road which ascends the hill to the northwest. Hand leveling from the base of the creek outcrops to the highest outcrop in the road shows that a minimum thickness of 70 feet of practically barren blue-green shale is present at this place. The only fossil collected was a single valve of *Hebertella sinuata prestonensis* n.var. Twinned and single crystals of selenite (gypsum) are plentiful on the weathered surface of the exposures along the creek. (See Plate XIII.)

Outcrops of this portion of the Brainard were found at many places, among which were the following: (1) southeast quarter of section 20, Pleasant Valley township, Fayette county, along the road paralleling Otter creek; (2) north of the center of section 24, Union township, Fayette county, north flowing tributary of Otter creek; (3) about one mile southwest of Eldorado, Dover township, Fayette county, along road, right bank of Turkey river; (4) west central part of section 29, Auburn township, Fayette county, right bank of Turkey river; (5) southeast quarter of the southeast quarter of section 1, Jackson township, Winneshiek county; (6) section 4, Washington township, Winneshiek county, along Fort Atkinson-Calmar road.

At the above localities, and many others as well, the Lower Brainard (i. e. all that part below the Cornulites zone) is the same; a bluish green shale which seems practically barren of fossils. At one locality, however, it seems to be highly fossiliferous. This is in the southeast quarter of the southeast quarter of section 25, Auburn township, Fayette county. Near this point the road crosses a small tributary which flows northeast to join Turkey river. In the bed of the creek above the bridge soft blue shale and slightly indurated limy beds are exposed for some distance. The soft shales are abundantly fossiliferous and the indurated slabs are covered with bryozoa, brachiopods and other forms. The assemblage is a mixed one, notable chiefly for the high percentage of bryozoa, the species *Dicranopora emacerata* being especially abundant. The fauna does not seem to contain *Cornulites sterlingensis,* which is the index fossil of the uppermost Brainard. The fossils appear to be limited to a two-foot zone but slabs are strewn along the creek banks for some distance. The writer did not find this zone duplicated at any other locality.

Twenty feet above this highly fossiliferous zone, downstream in a small gully which leads up to a farm house, a few fossils occur in the shale, all wide ranging forms. Up stream one-fourth mile the basal ledges of the Hopkinton outcrop 70 feet (hand-leveled) above the highly fossiliferous zone. The actual contact is not exposed, but an abundance of *Plectambonites* on a weathered outcrop immediately below suggests the Cornulites zone; in which case the remarkable fossiliferous zone first described must lie near the top of the lower half of the Brainard member (the maximum thickness of the Brainard is about 120 feet).

No. 13 of the General Section, Cornulites zone.—The classic exposure of this highest Maquoketa horizon is seen at Patterson's spring in the west half of the northwest quarter of section 20, Pleasant Valley township, Fayette county. The following section was taken at this place:

		Feet	Inches
8.	Basal ledges of the Hopkinton dolomite, containing characteristic corals, etc.	10+	
7.	Hard gray crystalline limestone interbedded with seams of plastic blue clay. In beds several inches in thickness. Poorly preserved fossils	3	
6.	Soft plastic blue clay; a variety of fossils similar to those occurring in the beds below	3	6
5.	Thin beds of crystalline limestone crowded with a great variety of fossils, some of the commonest being: *Cornulites sterlingensis, Hebertella sinuata prestonensis* n.var., *Plectambonites, Leptaena unicostata, Calymene gracilis,* and stem segments of *Dendrocrinus kayi.* Of these *L. unicostata* is by far the most abundant	5	
4.	Interbedded layers of yellowish fine-grained limestone and purplish blocks of shale. No fossils observed	1	3
3.	Soft extremely plastic non-gritty blue clay. No fossils seen	1	5
2.	Hard blue shale, fairly well bedded, much variation in thickness of beds	5	4
1.	Soft plastic blue shale, irregularly bedded and jointed	5	

This same horizon is exposed in the northwest quarter of the northeast quarter of section 36, Auburn township, Fayette county, and at a point north of the center of section 24, Union township, Fayette county, north flowing tributary of Otter creek. At the latter place the fossiliferous zone is thinner.

Southeast Area

Many of the characteristics of the formation as it is developed in the Southeast Area are well shown in a single section found two miles south of Bellevue in Jackson county. This section has been studied in detail. It will be mentioned first and other outcrops in nearby areas can be compared with it.

In the southeast quarter of section 29, township 86 north, range 5 east, a small creek is tributary to Mississippi river from the west. It flows in a steep walled gully which cuts the entire thickness of the Maquoketa shale. At the upper end of the gully the cherty fossiliferous beds of the basal Hopkinton can be seen in place and where the creek enters Mississippi river it flows over the thin crinoidal layers of the underlying dolomite. In this section conditions are not ideal for either the contact with the Galena or that with the Hopkinton. Recent erosion and deposition have obscured the lowest twenty feet of the Maquoketa and talus from the Hopkinton covers most of the upper fifteen feet. However, it is certain that the Galena layers do not extend much above the level of Mississippi river since they rise only a few feet above that level at Bellevue two miles north (the dip being south and west). The contact with the Hopkinton can also be located rather accurately by the presence in the creek bed of the fossiliferous slabs so characteristic of the uppermost Maquoketa. No Alexandrian strata are found in this locality.

As seen in the field the section is entirely of shale. Good outcrops are numerous at intervals over almost the entire distance. Typically the shale is greenish blue in color, well bedded, plastic, and exhibits conchoidal fracture. In thickness, type of fracture and hardness the outcrops differ slightly and occasionally banks of unbedded greenish or brownish sticky clay are encountered; many of these last are doubtless slumped and weathered shale outcrops but others seem to be in place. Fossils are rare and poorly preserved for the most part. Carbonaceous films of graptolites, chiefly *Diplograptus peosta* (?), are present 21 feet above the base of the formation and also at the 40 foot level. Similarly preserved remains of *Plectambonites* and some large strophomenids are abundant at about the 50 foot level. No other fossils were observed until a point 136 feet above the base was reached. Here occur numerous non-identifiable remains of brachiopods and other forms. A specimen of *Charactoceras laddi* Foerste n. s. was found in the float in the creek bed a short distance above the middle of the section. Near the top, as previously mentioned, the characteristic fossils of the Cornulites zone are numerous and well preserved.

Such a section as the above can not be divided into members on field evidence alone because in spite of its great thickness it is a lithologic unit and contains few well marked faunal zones to aid the investigator in recognizing horizons. The basal Depauperate zone, the Cornulites zone at the top and to a less extent the Graptolite zone seem constant in position and may be found at several localities. In the Graf area, however, some very remarkable fossiliferous beds are well developed in the lower part of the section. These seem to be absent in adjoining areas, hence the following discussion of "Typical Localities" is more or less local in application.

Depauperate zone.—For a discussion of this zone as developed in the Southeast Area see pages 377 to 384.

Graptolite zone.—The occurrence of this zone in the section two miles south of Bellevue has already been mentioned. It may also be seen at Bellevue in the shale pit several hundred yards above the mouth of Mill creek. Here it occurs between 25 and 30 feet above the base of the formation. Here also the graptolites are chiefly *Diplograptus peosta* and are preserved as carbonaceous films on the bedding planes of the green shales. Graptolites are extremely abundant in certain beds of the Graf section at about the same horizon.

Graf Section.—This section has been studied by a number of workers. Several of these have published detailed sections far more complete than the one the writer was able to make at the time of his visit. Thomas[117] seems to have seen the section as exposed in the railroad cut at the most favorable time, hence some of his observations are quoted below:

". . . . . The cut is located in the southwest quarter of section 29, township 89 north, range 1 east. A prominent hill or mound capped by a remnant of the Niagaran is located about one-fourth mile to the northwest of the exposure. The top of the hill is a little more than 200 feet higher than the roadbed of the railway for which the cutting was made. (For map, see the Peosta Quadrangle, United States Geological Survey.)

"The first cut in the foot of this hill was made by the Chicago, St. Paul and Kansas City Railway (now the Chicago Great Western) in 1886. Some time later the exposure was visited by Joseph F. James, of the United States Geological Survey, and the results of his studies were published in the American Geologist, Vol. V, pp. 335-356. James, however, did not limit his work to this artificial section but studied the shales with a view of correlating them with the Cincinnati group of southwestern Ohio. For this reason his studies included all the available Maquoketa exposures in the immediate locality and several of the fossils listed by him, on page 353, do not occur in the artificial section.

"Calvin and Bain gave a very careful and detailed section of the cut in the geology of Dubuque county, Iowa Geological Survey, Vol. X, pp. 435-436. Ten or twelve years of exposure to the weather, however, had so obscured the bedding of the upper part of the cut that little more than two-thirds of the section recorded by James was available for their study.

In 1911, the Chicago Great Western Railway Company had the hill cut back thirty-five feet, exposing a face approximately 900 feet long and thirty feet high. The base of this fresh section is not more than fifteen to twenty-five feet above the top of the Galena as may be determined by hand leveling from the contact in the stream bed a short distance to the northeast. Beds Nos. 1 and 2 given below correspond approximately to the upper seven feet of bed No. 5 of the section given by Grant and Burchard on page seven, Lancaster-Mineral Point Folio, United States Geological Survey.

The thicknesses of some of the members described vary somewhat from point to point but the following section taken at about 300 feet from the east end may be regarded as typical:

		Feet	Inches
30.	Clay shale, plastic, pebbleless, bluish gray, breaks with starchy fracture. Contains occasional flint chips and nodules. Grades upward into soil	3	
29.	Hard, yellowish, subcrystalline, slightly calcareous bed. It caps the highest parts of the indurated rock over most of the exposure. Contains broken tubes of *Coleolus* and fragments of other fossils	1	
28.	A lean fissile shale; seemingly barren		3
27.	Shale, dark gray to brown, nonlaminated, more or less nodular, fossils fragmentary	2	7
26.	Shale, brown to black, fissile, slaty when dry; seemingly barren	1	
25.	Shale, brown to gray, nonlaminated, quite fossiliferous in its lower part but barren at its top. Fossils small		9
24.	Shale, dark brown, laminated, occasional thin lenses and bands in lower part crowded with the tubes of *Coleolus*. The *Hormotoma* occurring at this level is invariably very small		8
23.	Shale, gritty, reddish brown, mostly disintegrated to a sort of clay parting. The clay is filled with an abundance of very small fossils and fragments of larger ones		2
22.	Shale, fissile, brown to black; tends to split into thin, lenticular, sharp-edged pieces. Fossils few, confined to lower part	1	
21.	Shale, gritty, nonlaminated, light brown, slightly calcareous, filled with fossils; The *Coleolus* tubes are especially abundant and, many of them being hollow, give the rock a porous appearance. (16)*	1	5
20.	Shale, fissile, forms a parting; seemingly barren		2
19.	Shale, drab, very fissile when fresh but weathers into shapeless chips and nodules. Impressions of *Spatiopora iowensis* and of the *Orthoceras* shells which they enclosed are common (15)	1	2
18.	Shale, brown to gray, nonlaminated, slightly calcareous. *Orthoceras sociale* abounds, the individual shells being often telescoped into each other. This is Calvin and Bain's fifth Orthoceras bed (14)		11
17.	Shale, remarkably fissile, slaty when dry, dark gray. A conspicuous horizon containing abundant impressions of the bladelike Bryozoan, *Spatiopora iowensis* (13)		6
16.	Shale, similar to No. 18 but more crystalline. Abounds in well preserved shells of *Orthoceras sociale*, while occasional fragments occur of a large Orthoceratite, elliptical in cross section, and certainly two or three feet long when whole. Calvin and Bain's fourth Orthoceras bed (12)		7
15.	Shale, brittle, nonlaminated, gray. Fossils few and very small (11)		3
14.	Shale, hard, gritty, similar to Nos. 18 and 16. Upper part more crystalline than the lower. *Orthoceras sociale* abundant but frequently dissolved away leaving hollow molds partly lined with crystals of calcite and pyrite and encrustations of limonite. This is Calvin and Bain's third Orthoceras bed (10)		7

* Numbers in parenthesis refer to practically equivalent members in the Calvin-Bain section, Iowa Geol. Survey, Vol. X, pp. 435, 436.

		Feet	Inches
13.	Shale, dark, occasionally fissile, often a mere parting. Contains a few fragmentary fossils (9)	1–3	
12.	Shale, brown to gray, nonlaminated, weathers very readily. *Orthoceras sociale* common and most of the individuals compressed as in No. 19, but the *Spatiopora* absent		5
11.	Shale, similar to No. 12 and has a band in which *Orthoceras sociale* occurs in profusion. This and No. 12 correspond to Calvin and Bain's second Orthoceras bed		6
10.	Shale, variable in coarseness and hardness, dark gray to black when moist, bluish and brown when dry, imperfectly laminated, earthy. A very fossiliferous zone characterized by the great abundance of *Coleolus iowensis, Diplograptus peosta* and many small gastropods (7)		6
9.	Shale, compact, dark gray, slightly calcareous, shows banding but is nonfissile; fossils small and broken (6)		6–7
8.	Shale, brown to drab, thinly laminated. Fossils few (5)		8
7.	Shale, gray to black, earthy; the upper two or three inches crowded with comminuted shells. Fossils numerous in part of this member	1	2
6.	Shale, reddish, soft, in places reduced to a clay parting; seemingly barren		1
5.	Shale, dark gray, brittle, nonlaminated; *Hyolithes parviusculus, Coleolus iowensis* and other small fossils stand out in relief on the surface of this member as it is weathered. Nos. 5, 6 and 7 are equivalent to (4)		7
4.	Shale, dark, slaty, breaks into angular pieces and fragments; comparatively hard when dry. There is a conspicuous *Coleolus* band near the middle of the member. Two or more species of *Lingula* and *Diplograptus peosta* are the most abundant fossils	3	7
3.	Shale, brownish gray, poorly laminated, compact. No fossils observed		3
2.	Shale, similar to No. 4 but bluer and more fissile. Locally the member contains dark fissile bands which carry abundant specimens of *Leptobolus occidentalis* and a minute ostracode	5	
1.	Shale, brown or black, nonlaminated, contains a few large Lingulas. Covered in large part by talus	2''	

The Orthoceras beds are also found in the northeast quarter of section 29, Center township, Dubuque county, six feet above a northwest flowing tributary of Little Maquoketa.

The Barren Middle Beds.—The great bulk of practically barren shale which intervenes between the basal fossiliferous zones and the Cornulites zone at the top outcrops at a large number of places, including the following: (1) northeast quarter of section 36, Mallory township, Clayton county; (2) northeast quarter of section 22, Elk township, Clayton county; (3) above the dam on Volga river at the town of Volga, Clayton county; (4) southeast quarter of section 22 and northeast quarter of northwest quarter of section 27, Mosalem township, Dubuque county; (5) northwest quarter of southwest quarter of section 21, Van Buren township, Jackson county; (6) southwest quarter of section 13 and east central part of section 14, Van Buren township, Jackson county;

(7) southwest quarter of section 14, Prairie Spring township, Jackson county; (8) section 14, Rice township, Jo Daviess county, Illinois, Great Western Railway tunnel; (9) four miles above the mouth of Establishment creek, Ste. Genevieve county, Missouri, immediately above Clement railroad station, left bank of creek.

The Cornulites Zone.—This horizon is very well exposed in the south-central part of section 29, Fairchild township, Jackson county. Immediately south of this point (i. e. in the north central portion of section 32) a small creek flows eastward, exposing the Hopkinton dolomite in its right valley wall and the Des Moines sandstone in its left (north) bank. Cutting through the latter are a number of tributary gullies and at the heads of several of these the uppermost Maquoketa layers are exposed. They consist of a series of alternating bands of shales and limestones. Few beds are actually seen in place. The shales are greenish blue and highly fossiliferous and give rise to weathered banks where collecting is excellent. The thin limestone slabs are crowded with fossils, of which *Plectambonites* and branching bryozoans are the most abundant.

Practically all of the species reported from this zone in the southeast area may be found at this one locality. Other exposures were seen as follows: (1) section 3, Taylor township, Dubuque county, cuts on the Chicago Great Western railroad; (2) southwest quarter of section 13, Van Buren township, Jackson county, along northwest-southeast road; (3) section 23, Van Buren township, Jackson county, along east-west road north of the center of the section; (4) north-central section 16, Washington township, Jackson county, along a small creek flowing parallel with the road; (5) southeast quarter of section 29, township 86 north, range 5 east; (6) southwest quarter of section 13, Elk River township, Clinton county, left bank of small creek; (7) Reservoir Hill, Stockton, Jo Daviess county, Illinois; (8) quarry one-fourth mile northwest of Stockton, Illinois; (9) northwest quarter of southwest quarter of section 21, Woodbine township, Jo Daviess county, Illinois; (10) northwest quarter of section 1, Hanover township, Jo Daviess county, Illinois, gully 1¼ miles north 5° east of Pleasant Hill School, just north of the Burke home; (11) Savanna, Illinois, north edge of town, base of cliff below farm owned by Mr. Clay.

EVIDENCE OF UNCONFORMITIES

Dubuque-Maquoketa Contact.—According to previous Iowa Survey reports, all the beds intervening between the Decorah shale and the Maquoketa shale belong to one formation, the Galena, formed during the Mohawkian epoch of the Ordovician. The Galena, as thus defined, is not a unit. In 1907, Sardeson suggested that the "strata of irregular limestone and interlaminated carbonaceous shales, which extend at Dubuque, Iowa, from the 'cap rock' to the blue shales of the Maquoketa proper" (95, p. 193) be given the name *Dubuque formation.* This formation coincides with the *Triplecia* bed as previously defined (93, pt. 2, pp. 21-24). In Iowa *Triplecia* has not been found, but the zone is characterized by abundant specimens of *Lingula iowensis* (Owen) and seems to be bed 15 of the section at Dubuque as given by Calvin and Bain (14, p. 429). Ulrich states that the same bed is exposed in the valley of Turkey river between Elkport and Elkader, there, as at Dubuque, directly underlying the Depauperate zone of the Maquoketa. In Wisconsin, about eight miles east of Boscobel, the Dubuque contains eight feet of shale.*

It is believed that the Dubuque is Richmond in age. The evidence is not conclusive because the fauna has never been carefully studied. The well-known species *Lingula iowensis* (Owen) is more closely related to *L. quadrata* Eichwald from the Richmond (Lyckholm) of Russia than to any other known species of the genus. Some of the species of *Dalmanella* occurring in the Dubuque are likewise very close to typical Richmond forms. Future work should yield a great deal of valuable information and should make possible a correlation between the Dubuque and other pre-Maquoketa Richmond rocks found to the south of the Iowa area.

The exact distribution of the Dubuque is not known with certainty and for this reason the term *Galena* is in some cases placed in quotation marks in the detailed sections given on pages 376 to 380. Some of these beds that immediately underlie the Depauperate zone will, in all probability, eventually be referred to the Dubuque.

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* Ulrich, E. O., written communication, October 27, 1925.

In certain localities in Iowa there are beds beneath the Dubuque that may be Richmond and therefore not a part of the Galena. Ulrich noted the following section at Elkader, Iowa.*

	Feet	Inches
Dubuque dolomite		
11. Shale, brown below, with a one foot layer of fine earthy dolomite	4	
10. Phosphate	6	
9. Irregularly bedded, yellowish dolomite with seams of shale. Coarser than above. No fossils in upper half but in lower third the shaly seams are filled with crinoid buttons	10	
8. Chocolate colored shale and slightly magnesian fossiliferous limestone	1	4
7. Bluish, moderately magnesian limestone in layers 1 to 2 inches. Rather highly fossiliferous, *Dalmanella,* massive bryozoa, crinoid buttons, etc.	8	6
6. Chocolate colored shale	1	2
5. Yellowish dolomite, filled with fucoids	3	6
Questionable beds		
4. Grayish yellow to bluish, granular, vesicular dolomite. *Sinuites, Cyrtoceras* and unidentifiable fragments. Molds of crinoid buttons rather common	25	
3. Yellowish, rather dense, magnesian limestone. No fossils	45	
2. Covered	15	
Galena formation, Fusispira bed.		
1. Cherty beds	45–55	
Ischadites and other fossils just beneath and perhaps still within the cherty horizon.		

Studies are now under way which will, it is hoped, determine the exact age of beds 2 to 4 in the above and in similar sections in nearby areas.

There seems to be no evidence of a distinct *erosional* unconformity between the Maquoketa and the underlying rocks in the upper Mississippi valley. Thus, Trowbridge and Shaw in their report on the geology of the Galena and Elizabeth quadrangles in Illinois, state that in the Galena formation "the upper *Receptaculites* zone lies everywhere about 70 feet below the top of the formation" (122, p. 71). Calvin and Bain,[(14)] working in Dubuque county, Iowa, had previously come to the same conclusion though James (51, p. 349) had stated that he had found evidence of pre-Maquoketa erosion in the same area. Calvin and Bain, in describing the locality mentioned by James, state the following (14, p. 40):

"From observations in the bed of the stream, made at what seemed to be the line of contact between the two formations, James . . . . reached the conclusion that the shales are separated from the limestones by an unconformity. It is just possible that the author referred to, with observations limited to

* Ulrich, E. O., written communication, March 16, 1928.

the narrow dimensions of the creek bed, was misled by overwash of clay upon recently eroded Galena.''

The writer visited this particular locality and found the irregular contact. Thin beds of dolomite outcrop as described to a thickness of 15 feet. This exposure is in a valley wall. Upstream some distance and immediately above the creek level the top of the dolomite is visible for several yards. Overlying this is a zone of clay showing at its base a band of bright red-brown material which follows the top of the dolomite rather closely. Above are irregular veins and blotches of similar material. Washing and sieving of a sample taken just above the contact revealed a few minute phosphatic pellets, one specimen of *Coleolus iowensis,* and one segment of a crinoid stem (probably from dolomite). Here fossils are almost entirely absent though lithologically the zone resembles basal Maquoketa. Upstream a hundred yards the contact of clay and dolomite is again exposed but here the latter is not noticeably eroded. Lithologically the clay appears identical with that observed downstream but washing showed numerous phosphatic pellets and the following fossils:

Hindia parva (?) Ulrich
Diplograptus peosta Hall
Leptobolus occidentalis Hall
Lingula sp.
Conotreta obliqua n.s.
Dalmanella sp.
Ctenodonta fecunda (Hall)
Priscochiton elongatus n.s.
Pleurotomaria depauperata (Hall)
Liospira micula (Hall)
Coleolus iowensis James
Orthoceras sociale Hall
Ostracodes (undet.)
Drepanodus acinaciformis n.s.

There seems to be little evidence of an erosional contact at this place. Perhaps, as Calvin and Bain suggested, James was misled by ''overwash of clay upon recently eroded Galena''.

Even though it be admitted that there seems to be no real evidence of a distinct erosional break between the two formations it does not follow that the two are conformable. The distinctness of a stratigraphic break does not always reflect the duration of the time interval involved. Despite the absence of a distinct break the Eden and Maysville groups of the Cincinnatian series are not represented and there are several other types of evidence which bear upon the question:

(1) The phosphatic character of the basal Maquoketa. It is a well established fact that phosphate beds often occur at stratigraphic breaks. Goldman[33] has summarized the evidence supporting this principle. The Depauperate zone of the Maquoketa exhibits many of the peculiarities usually associated with such beds. The zone is phosphatic wherever found and the phosphatic material is not limited to certain nodules. The entire zone is phosphatic, including fossils, matrix, nodular masses, minute pellets, and large pebbles.

The nodular masses are irregular and of doubtful importance. The minute pellets are flattened oval in shape and one millimeter or so in diameter. They are smooth and remarkably regular in form. Usually they show a varnished surface, which may be due to the deposition of a ferruginous film. Many large pebbles and the upper surface of the underlying dolomite in places show the same effects. It is possible that many of the minute pellets represent the worn internal molds of ostracodes, small pelecypods, etc. Many of the larger fossils show some evidence of mechanical wear. The upper layers of the underlying rocks rarely show even a trace of phosphatic material and the same is true of the shales overlying the Depauperate zone, except in one locality; this is at Graf, Iowa. Here the larger forms of the fauna range upwards* for thirty or forty feet. These include at least one-third of the fauna and the beds containing them are highly phosphatic.

In discussing the interpretation of phosphate zones in general Goldman states:[33]

"A long period during which the sea bottom was at or near marine base-level seems to be implied in any case, and that, so far as I can see, implies also an approximation to subaerial base-level of the adjacent land."

(2) The presence of pebbles. These are mechanically worn, also pitted as though by solution (see Plate XIV, also a paper by Savage and Ross, Amer. Jour. Sci., 41, p. 192, 1916).

(3) A distinct lithologic change. Though the upper layers of

* It is possible that many of the smaller ones do also. This section has not yet been studied microscopically.

the dolomite do contain small amounts of shale they in no way resemble the shales of the basal Maquoketa. The contact, where well exposed, is everywhere as sharp as a knife-edge. There is no evidence of transition.

(4) An equally distinct faunal change. The Depauperate fauna, which is invariably found at the base of the Maquoketa, has no counterpart anywhere in the underlying beds. In fact, of the forty species occurring in this fauna not one has been reported from a lower horizon. It is true that there are several genera in common but this is to be expected in adjacent formations of the same system, even when *distinctly* unconformable.

(5) The widespread occurrence of oxidized iron (limonite) which suggests exposure to the atmosphere in pre-Maquoketa times (122, p. 71). To be sure this is not highly significant as it may be explained as a product resulting from the recent weathering of abundant pyrite.

(6) The presence of a distinct erosional unconformity beneath the Maquoketa to the south in Illinois and Missouri, where the formation overlies the Kimmswick limestone. In one place at least, a residual soil, bearing angular fossiliferous pieces of chert, occurs beneath the Maquoketa, as reported by Weller(147) (see also detailed description on pages 381 and 382).

The Maquoketa-Alexandrian contact.—The term *Alexandrian* was proposed by Savage in 1908 to include certain "Middle Silurian strata that more or less completely bridge the lost interval between the Cincinnatian and the Clinton".(98) The type exposures were described from Alexander county in Illinois. (These rocks were referred to the lower Silurian in papers which followed.) In a later paper Savage recognized two rock formations of this series, the Winston and Waucoma limestones, as occurring in Iowa.(100)

Regarding the first of these, the Winston limestone, he writes as follows (pp. 34 and 35):

"Early Silurian strata representing the Edgewood period of deposition were first recognized in Jo Daviess county in an exposure about six miles southeast of Galena Junction, in the cut at the station of Winston at the south end of the tunnel made by the Chicago Great Western Railroad, where the following section was made:

Section at Winston, at southeast end of Chicago Great Western Tunnel.

	Feet
Alexandrian limestone	
3. Dolomite, yellow, earthy, fine-grained, in rather thin, even layers	22
2. Sandstone, bluish, calcareous and shaly, conspicuously laminated	½
A break in sedimentation	
Maquoketa shale	
1. Shale, bluish gray, without fossils	7

Following this the author gives considerable paleontological evidence, states that the rocks described also occur at other points in northwestern Illinois and northeastern Iowa, and proposes the name *Winston limestone,* which "as here defined includes only the lower part, below the cherty dolomite, of the division designated by Wilson as the basal member of the Niagaran limestone of northeastern Iowa" (p.35).

Regarding the distribution of these rocks in Iowa, Savage speaks of their occurrence in Jackson county, where they overlie the Maquoketa and are overlain by the cherty lower horizon of the Hopkinton dolomite. He cites a thickness of about 40 feet in the northwestern part of Bellevue which "decreases southward so that less than 18 feet are present at Savanna, Illinois", and is "seen to feather out in the river bluff between Sabula and Elk River, Iowa" (p. 35).

The second of Savage's Alexandrian formations is called the Waucoma limestone. The rocks of this formation are described by him as follows:

". . . . . . present in Jo Daviess county, Illinois, and occur farther northwest in Iowa. The best exposures known are along Little Turkey river in Fayette county, Iowa, where a ledge of light gray, nonmagnesian limestone 10 to 20 feet thick outcrops in several places between the villages of Waucoma and Auburn. This limestone rests unconformably upon the Maquoketa shale, the Winston limestone being absent in this region. It is succeeded by normal Hopkinton dolomite of Niagaran age. An outcrop of this limestone in the banks of the river three miles southeast of Waucoma furnished the following fossils. . . . ."

Following this is a list of fifteen fossils which "indicate for this limestone an age nearly equivalent to the . . . . Brassfield of Ohio. . . . . . ."

Recently Savage has published another paper(103) in which he reviews his earlier work and abandons the terms "Winston" and "Waucoma", substituting Edgewood and Kankakee (Brassfield) respectively. The type locality of the former is in Missouri, the latter in Illinois. He correlates the "Burroughs dolomite" of Ulrich* with the Edgewood and Kankakee and advances the belief that, together with all the other Alexandrian strata of Illinois and Iowa, these rocks were deposited in a sea that advanced from the south.

Previous to Savage's work on these rocks they had received little or no detailed study from the different workers who had encountered them in Iowa. In the year 1898 Calvin, in discussing the Maquoketa shales of Delaware county, described a section exposed at the mill dam at Rockville. He spoke of part of this section as "transition beds that record the passage from the conditions of deposition which gave rise to the blue shales, to those represented by the Niagara dolomite."(11) So far as the writer is aware, this was the first usage of the term "transition beds" as applied to strata overlying the Maquoketa and underlying recognizable Niagaran horizons. The Delaware County report was the first of eight published by the Iowa Geological Survey in which the Maquoketa shales were discussed. From first to last this term "transition beds" was applied by the Survey as a name for all rocks between the upper blue shales of the Maquoketa and the cherty layers of the Hopkinton. As originally used by Calvin the term applied to a thickness of 25 feet of argillaceous yellow limestone, containing *Dalmanella testudinaria* in the basal portions and being barren and more calcareous toward the top. In later reports it was applied also to rocks of an entirely different sort, but occupying the same stratigraphic positions, described later by Savage as the Winston beds. Since none of these beds are transitional in the true sense of the word, being separated from the Maquoketa below and from the Hopkinton above by well marked unconformities, it seems desirable to drop the usage altogether and accept Savage's two formations—the Edgewood and the Kankakee (Brassfield) limestones.

At the present time the writer does not have sufficient data at

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* Reference 136. In this paper Ulrich proposes the name Burroughs dolomite for certain strata at Savanna, Illinois, "Near the top of Burrough's Bluff, ... and also in and above Charles Miles' quarry near the southeastern edge of the same city". He lists 25 fossils, provisionally identified, which support his belief that the rocks are clearly post-Richmond and pre-Clinton. He assigns the formation to "some part of the intermediate Upper Medina stage in which the Edgewood formation of Missouri is probably a nearer contemporary than the Cataract of Ontario". He points out that the beds are lithologically quite different from the Edgewood and expresses the belief that they might not be strictly equivalent. At the present writing he still questions the Edgewood age of the rocks referred to the Burroughs. (Oral communication March 16, 1928.)

hand to give an accurate description of the distribution of the Edgewood limestone, but it is certain that it is found scattered over most, if not all, of the Iowa area. Savage has described its occurrence in Jackson county. North of here in Dubuque county, it is typically exposed in the southeast quarter of section 22 and the northeast quarter of the northwest quarter of section 27, Mosalem township. Here, as in Jackson county, it overlies barren Maquoketa shales and seemed to contain no identifiable fossils except a *Dalmanella* sp., and a poorly preserved *Lingula*. The recognition of the formation is made purely on lithologic characteristics and stratigraphic position, but so distinct is the former that the writer feels no hesitation in referring these beds to the Edgewood as developed to the south in Jackson county and at Winston, Illinois. Similar conditions are encountered in the northeast quarter of section 22, Elk township, Clayton county. Even farther to the northwest the same formation is seen overlying the Maquoketa. The following section is exposed immediately north of the center of section 24, Union township, Fayette county:

Exposure in north flowing tributary of Otter creek.

		Feet	Inches
4.	Gray dolomite in massive beds approaching 1 foot in thickness. Fragments of fossils as molds	3	
3.	Hard yellowish finely laminated layers. Argillaceous and calcareous	1	
2.	Comparatively soft, poorly bedded gray-blue shale	1	3
1.	Thin brown ferruginous zone, underlain by plastic blue Maquoketa shale containing limestone slabs covered with Maquoketa fossils of the Cornulites zone		5

Other localities might be described but it is believed that sufficient evidence has been given to show that the Edgewood as a distinct Alexandrian formation is somewhat widely developed in Iowa and that where found it is plainly separated from the Maquoketa by an unconformity.

During the present investigation the writer visited the exposures near Auburn, Iowa, which were originally designated the type sections of the Waucoma—now known as the Kankakee limestone. Following Little Turkey river from the town of Waucoma toward Auburn first outcrops of the formation were found in the southeast quarter of section 30, Auburn township. This is at least five (not three) miles from the town of Waucoma and on the contact as mapped by Savage in 1905. The exposure is in the right bank of a small creek tributary to Little Turkey from the south 1325 paces along the road northeast of the road fork mapped in the south-central part of section 30, Auburn township. Here three inches of argillaceous, arenaceous dolomite underlies nine inches of basal conglomerate, which in turn is overlain by several feet of even textured finely laminated blocky material. Superficially weathered yellow blocks show a bluish interior. Lithologically, as seen in the field, this part of the section is identical with the Edgewood as seen in Jo Daviess county, Illinois.

Near the above described outcrop, in about the west central part of section 29, Auburn township, fifteen feet of apparently barren Maquoketa shale are seen overlain by the Kankakee beds (rock similar to basal member of above section). The contact is irregular, owing probably to slumping. However, the relations are evidently those of unconformity. The upper fossiliferous zone of the Maquoketa is not present.

FIG. 68.—View of the chert-bearing beds of the Iowa Hopkinton dolomite. Along road east of Preston, Jackson county, Iowa.

The Alexandrian rocks of Iowa have never been carefully mapped and studied. Such treatment will be necessary before their exact age and stratigraphic relations are fully understood. Where present they rest unconformably upon the Maquoketa, for older Silurian rocks are missing. Thus in southwest Illinois and in adjacent portions of Missouri the Orchard Creek shale and the Girardeau limestone, both Alexandrian in age, lie between the Edgewood and the older Richmond beds.

The Maquoketa-Niagaran Contact.—Over most of the Iowa area the Maquoketa is overlain directly by the Silurian formation known as the Hopkinton dolomite. This formation is a part of the Niagaran series of the Silurian. Its relations to the Maquoketa are clearly those of unconformity since all Alexandrian and Clinton rocks are missing. Locally basal conglomerates in the Niagaran have been reported. Two such instances have been

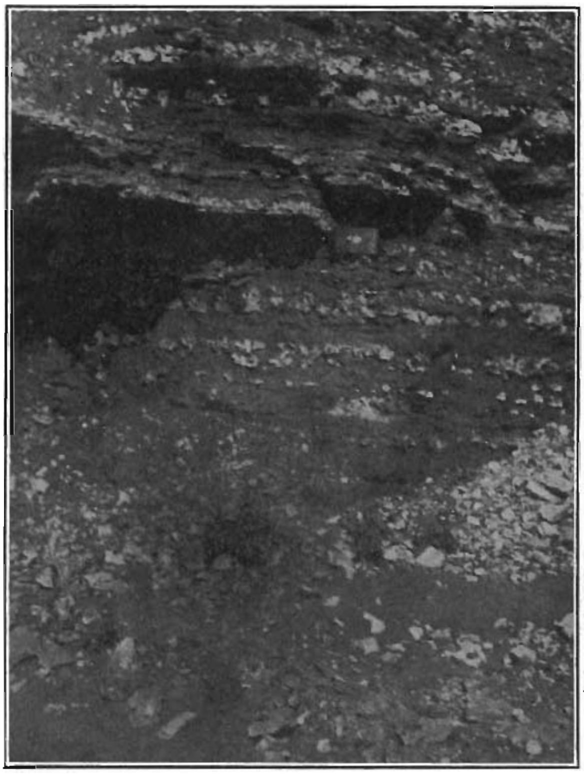

FIG. 69.—Another view of the cherty beds Same location as figure 68.

cited from Jo Daviess county, Illinois (122, pp. 72, 73). The present writer visited both of these localities. In the first one described in the above report as occurring "in the gully 1¼ miles north 5° east of Pleasant Hill School, just north of the Burke home in the northwest quarter of section 1, township 26 north, range 2 east (Hanover)" he found limestone slabs of the Cornulites zone overlain by soft Maquoketa shale, this in turn overlain by a brownish highly oxidized layer one inch more or less in thickness. Succeeding this there was a hardened layer containing typical Maquoketa fossils and the well rounded pebbles mentioned by the authors quoted above. Barren Niagaran succeeded this. Bedding in the contact zone was very irregular. The writer's observations agree perfectly with those given by Trowbridge and Shaw save that the conglomerate appears to be *in the upper Maquoketa* rather than in the lower Niagaran. The fossils appeared fresh and unbroken, showing no evidence of having been reworked by an advancing sea. The pebbles of this conglomerate are comparable to the large smooth dark pebbles occurring numerously in the upper Maquoketa of Jackson county, Iowa, across the river. (See Plate XI.) Their origin and significance seem uncertain.

The contact at the second locality mentioned by Trowbridge and Shaw was not well exposed at the time of the writer's visit. However, the Upper Maquoketa shales contain smooth black pebbles similar to those of Jackson county, Iowa, referred to above.

In some localities the normal Hopkinton dolomite overlies the Cornulites zone of the Maquoketa, at other points the Cornulites zone is absent and the lower Hopkinton beds rest directly upon barren Maquoketa shale. An example of the former relations may be seen in the southeast quarter of section 29, township 86 north, range 5 east, and an example of the latter may be seen in a small valley about one mile northeast of Clermont, in Fayette county, Iowa, on the land of Mr. Larrabee. It is also a fact that in cases where the Cornulites zone is present the Maquoketa is thicker than it is where this zone is absent.

Obviously these facts may be interpreted in either of two ways:

1) Assuming that the Cornulites zone was once spread more

widely over the area in question, its absence would mean post-Maquoketa-pre-Niagaran erosion on a rather large scale.

2) It may be assumed that the beds of the Cornulites zone were deposited only in certain tracts—in shallow, restricted basins—in which case the absence of the zone in certain localities is not to be used as evidence favoring a great unconformity at the top of the Maquoketa.

At the present time the writer is inclined to favor the former view but there is much to be said for either interpretation. Before the question can be settled definitely certain data not now available must be gotten. It is the writer's intention to discuss the question fully in a later part of this work.

There is at least one place in Iowa where the beds of the "Neda Iron Ore" occur between the Maquoketa and the Silurian. The name Neda was proposed by Savage and Ross in 1916[104] for the isolated patches of red oölitic ore correlated by Chamberlin with the Clinton ore of the Appalachian region.[16] Recently Howell has described a single occurrence of the rock in Iowa. It outcrops on the west side of Lore Hill about seven miles west of Dubuque[49] (northeast quarter of the southwest quarter of section 13, Center township, Dubuque county). The writer visited this locality but found the exposures described by Howell to be badly slumped. Overlying the red oölitic bed the writer found loose slabs of finely laminated dolomite similar lithologically to the Alexandrian beds. Howell identified a number of Niagaran fossils found in a small quarry 21 feet above the iron bed on the north side of Lore Hill but found no exposures below this. The stratigraphic relations of the Iowa outcrop are still in doubt as none of the overlying rocks are well exposed near the contact. Savage and Ross believe that the similar Neda deposits of eastern Wisconsin are late Maquoketa in age and Howell has correlated the Iowa outcrop with those of Wisconsin. These opinions seem well founded and the deposits have been interpreted as having been formed "in local but apparently connected basins (because of marine fossils) during late Maquoketa (Richmond) time, and after the main portion of the normal marine Maquoketa sea had withdrawn from the greater part of the region. . . . ." (104, p. 192).

Ordovician-Silurian Boundary.—During recent years there has been a great deal of discussion regarding the location of the boundary between the Ordovician and Silurian systems. The question is an important one and cannot be settled by the evidence available in any one locality. To speak with authority one must be familiar with conditions as they exist over wide areas. The detailed studies of the writer were confined almost entirely to the state of Iowa and he, therefore, is not in a position to discuss the question at length. For an extended discussion the reader is referred to some of the writings of Ulrich,(131, 132, 133, 138) Jones(53) and Schuchert.(110)

The most important question is the age of the Richmond, whether it is Ordovician or Silurian. Authors disagree upon this subject because they have applied different principles of correlation. The present writer agrees fully with Ulrich and with others who have adopted his views, who believe that diastrophism and its displacement of the strand-line form the ultimate basis for locating stratigraphic breaks and that fossils are to be used "to identify *horizons* and *not to decide how the division of geologic time into epochs and periods is to be carried out*" (133, p. 488).

With this principle in mind, several of the more important observations may be mentioned:

(1) The Richmond submergence was one of the most widespread of all geologic time. The series transgresses over enormous areas and may be seen lying directly upon various horizons from Cincinnatian to Cambrian.

(2) A great faunal break actually occurs at the base of the Richmond. Some 20 typical Silurian genera and 4 new families appeared in the Richmond, and the specific break is almost complete.

(3) In New York the Ordovician-Silurian boundary was drawn strictly according to diastrophic criteria and the barren Queenston division of the Medina was placed in the Silurian. It has since been shown that the fossiliferous beds of the Ohio valley Richmond finger into the Queenston and are therefore Silurian in age.

(4) In the Mississippi valley the Maquoketa shale is of Richmond age and in many places is underlain by older rocks of unquestioned Richmond age. These older ones are even more widespread than the Maquoketa and extend far beyond the limits of

the Maquoketa basin. In Iowa they are probably represented in the Dubuque dolomite, but this formation is not highly fossiliferous and has never been carefully studied. Hence, the base of the Richmond, *as now known,* is obscure in this area.

At the present time the writer believes with Ulrich that the Richmond belongs in the Silurian. However, until the studies of the pre-Maquoketa Richmond rocks of Iowa are completed and we know exactly where to draw the line at the base of the Richmond, it seems advisable to retain the Iowa Richmond in the Ordovician.

Maquoketa-Devonian Contact.—In northern Iowa and southern Minnesota the Maquoketa shales are overlain directly by rocks of Upper Devonian age. The break here is enormous and for a long time the facts concerning it were not appreciated by geologists. Sardeson[(92)] was the first to describe the occurrence of Devonian strata overlying the "Wykoff beds".* Several years later this contact was briefly mentioned by Winchell and Ulrich as follows:

"Succeeding the foregoing bed and followed with not very strong evidences of unconformity by Devonian strata, is a sandstone four feet thick which here and there contains large numbers of small quartz pebbles, varying between one and ten mm. in diameter. This sandstone we assume to belong to the Oriskany of New York" (165, p. cv).

The Iowa Geological Survey recognized the presence of the Devonian over the Maquoketa in 1903[(12)] but did not report the presence of the basal conglomerate and sandstone.

The valley of Upper Iowa river a mile or so above what was formerly the town of Florenceville† was found to be a very favorable place in which to study the contact in question. In section 9 of Albion township the steep valley wall of the right bank is pierced at intervals by narrow tributary gullies with rocky floors. A number of these were ascended and sections taken. All are quite similar and one example will suffice.

* The "Wykoff beds" as defined by Sardeson form the upper part of the "Maquoketa series" of Minnesota. In the terminology adopted in the present paper they consist of the upper portion of the Elgin member.

† The "town" of the early survey reports ceased to exist as such with the passing of the post office a number of years ago. The dam is broken and the mill stands idle. A few houses are scattered here and there but these had best be claimed by the town of Granger just across the state line.

A north-to-south section up a tributary entering right bank of Upper Iowa river, center section 8, Albion township, Howard county, Iowa.

	Feet
Soft brown earthy dolomite containing Devonian fossils. Several feet.	
Green shale	2
Friable white conglomerate sandstone	2
(unconformity)	
Upper Elgin beds, very fossiliferous at top. Exposed almost continuously from a point 6 feet 6 inches above river	33

Along the north-south road a little north of the center of section 22 of the same township similar sections are exposed. The Elgin beds are covered, the conglomerate appears in two different beds, separated and capped by green clay. A sack of the latter was washed through a fine sieve but no fossils were found.

In Winneshiek county the Maquoketa-Devonian contact may be seen at many places for the Devonian extends as a narrow tongue capping the Maquoketa on the Cresco-Calmar ridge for a distance of almost twenty miles. This tongue parallels the main contact which lies a short distance to the southwest across the valley of Turkey river. In the southeast quarter of the southeast quarter of section 1, Jackson township, Winneshiek county, the Maquoketa-Devonian relations are well shown. The Brainard shale outcrops along the road and has a possible maximum thickness of eight feet as limited by Fort Atkinson outcrops below and Devonian above. Apparently pre-Devonian erosion removed over 100 feet of shale at this point.

Maquoketa-Des Moines Contact.—In the north-central portion of section 32, Fairfield township, Jackson county, Iowa, the Maquoketa is seen to be overlain directly by the beds of a small Pennsylvanian outlier. Silurian rocks are in place close by. The Des Moines sandstones of lower Pennsylvanian age outcrop on a hillside which forms the north bank of a small stream which flows west to east. This hill has been cut by small tributary creeks flowing south. In these tributary gullies the highly fossiliferous indurated and shaly layers of the Cornulites zone outcrop. At a horizon almost immediately above them the Pennsylvanian sandstones can be seen in place with no Silurian strata intervening. Evidently the Maquoketa had been but little eroded in pre-Pennsylvanian time. A few rods to the south the Hopkinton dolomite can be seen in place in the opposite valley wall.

As explained elsewhere these unusual stratigraphic relations seem to be due to arching of the strata in post-Niagaran-pre-Pennsylvanian time.

STRUCTURE

In common with all the other Paleozoic rocks of northeast Iowa the strata of the Maquoketa dip gently to the southwest. This dip is not easily detected in most places, owing either to its gentleness or to local slumping. In a few localities minor folds and gentle reverse dips are observable in the Maquoketa and the other Paleozoic formations. In Allamakee county Calvin (9, p. 86) notes what McGee called the Sny Magill anticline traversing that area from southeast to northwest. Similar structures are noted in Clayton county (69, p. 289) and Fayette county (96, p. 532). Reversed dips in rocks younger than the Maquoketa show over a considerable part of Delaware county (11, p. 179), while in Dubuque county a series of low folds having an east-west trend is observable in some places. The most pronounced of these is the Eagle Point Anticline in the Galena. This deformation, though on a small scale, caused joints and fissures of importance in connection with lead and zinc deposition (14, p. 478).

Probably the most conspicuous example of deformation in the whole area is found in Jackson county and according to Savage (97, pp. 640, 641)

"consists of a low arch that extends in an east and west direction from Savanna in Illinois, to the east side of section 30 in Fairfield township, a distance of about twenty miles. The strata involved in the deformation embrace the Maquoketa shale and the overlying beds of Niagara limestone.

"The maximum measured height of the arch was in sections 29 and 30 of Fairfield township. At each of these points the aneroid readings gave the elevation of the upper layers of the Maquoketa as 175 feet above the corresponding layers in the vicinity of Preston. Readings at two different points in sections 22 and 23 of Van Buren township gave the altitude of the uppermost Maquoketa layers as 90 and 115 feet respectively above the equivalent layers near Preston. At some points over this arched belt, where the upper layers of the Maquoketa were best exposed, they seem to have been thrown into a series of small crumples at the time the main arch was raised. Where well exposed the layers are crossed by two series of small parallel fissures. These fissures are 6 to 24 inches apart and extend for a distance of one to three or four feet. Those of one series have a direction nearly at right angles to those of the other. When the Niagara layers were seen in an apparently undisturbed position against the inclined Maquoketa beds, the angle of dip was about 30 degrees. Between different points, and sometimes in the same outcrop, the dip varies widely as regards both direction and inclination. A portion of this variance is probably due to the fact that the Niagara limestone creeps or settles on the shale when inequality of support results from differential erosion."

This arch described by Savage is responsible for the inlier of Ordovician previously mentioned. Since the Silurian beds are involved in the arching its date is post-Niagaran. The Maquoketa shale and overlying Hopkinton dolomite were brought to a higher elevation in the Preston area than elsewhere and the former was exposed by erosion in pre-Pennsylvanian time, because the Des Moines sandstone lies undisturbed upon the Maquoketa. Considerable additional erosion by Mississippi river and its tributaries took place during the Pleistocene when that stream was forced westward by the advancing Illinoian ice.

Local deformation of an interesting character is here and there developed by the creeping of the heavy Niagaran beds on the softer underlying materials. Figure 70 shows an example of this. This picture was taken 529 paces northwest of the road along the small creek in the southwest quarter of section 15, Prairie Spring township, Jackson county. The point of the hammer rests on the soft, much-contorted, green shales above which

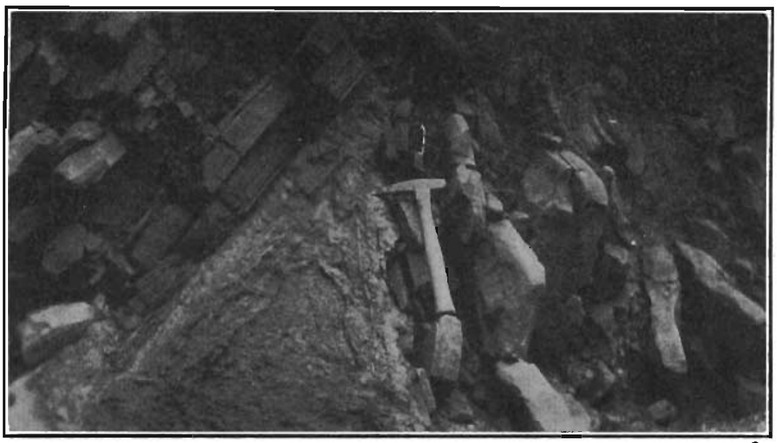

FIG. 70.—Small slump fold involving the Maquoketa shale and the overlying Edgewood beds. Southwest quarter, section 14, Prairie Spring township, Jackson county, Iowa.

are the fractured and broken fine-grained dolomitic Edgewood beds. Gigantic Niagaran blocks slipping down the sides of the steep walled valley have caused much buckling and folding in this locality. A similar occurrence is pictured by Savage in his Fayette county report (96, p. 472, fig. 40).

In summary it may be said that although small structures exist in a few localities the rocks of the region as a whole present a monocline dipping almost uniformly to the southwest. This dip is the largest factor affecting the topography so characteristic of the region.

CORRELATION

With the Richmond of Michigan.—The Richmond rocks of Michigan are found in the Upper Peninsula. They probably outcrop at several places from Drummond Island westward, but published accounts seem to deal only with the exposures in the Little Bay de Noquette district. This district was the only one visited by the writer and forms the subject of the brief discussion which follows.

A short and broad peninsula extends southward from the northern shore of Green Bay. On the west this peninsula is separated from the mainland by Little Bay de Noquette, while on the east it is separated from a longer and narrower peninsula by Big Bay de Noquette.

The Richmond rocks are exposed in the western peninsula along the eastern shore of Little Bay de Noquette. These form the upper part of the section as the dip is to the southeast. This part of the section was not visited. At the head of Little Bay de Noquette two streams enter; Rapid river, a small stream from the north, and (less than a mile eastward) Whitefish river, a larger stream from the northeast. Two tributaries of the latter stream cross the strike of the rocks and enter the Whitefish from its left bank. These last two, Bill's creek to the south, and Haymeadow creek to the north, expose parts of the lower Richmond section in their beds. (See fig. 71.) These were among the exposures visited.

As mentioned in the Historical Sketch above, Hall, in 1851, wrote concerning the "Hudson-river Group" of the Little Bay de Noquette district. He said (42, p. 149):

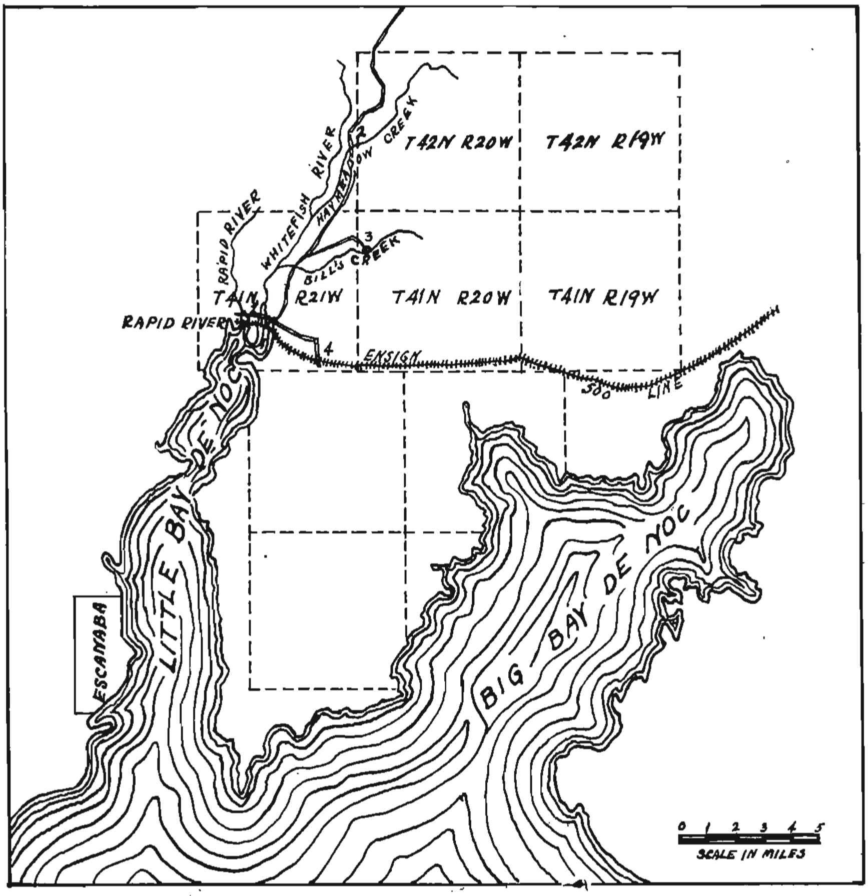

FIG. 71.—Map of a part of the Upper Peninsula of Michigan showing localities visited. (Outline after Hussey.)

"A single thin stratum is charged with small *Nucula, Cleidophorus,* and minute Gastropoda. Another calcareous layer is partially filled, and the upper surface covered, with fragments of *Isotelus.* . . . . In the succeeding beds there are some thin, calcareous layers, with *Orthis testudinaria* and *Spirifer lynx.* . . . ."

Hall saw the possibility of correlating these rocks with those of the Upper Mississippi valley on the basis of the zone of small molluscs.

At a later date Rominger[89] wrote in more detail concerning the area, identified a number of fossils, mentioned specifically the Bill's creek section and noted that, "The similarity of these beds with the shales representing the Hudson River group in the lead regions of Illinois and Iowa is very obvious. . . . ."

In 1918 Foerste[29] discussed the exposures of Richmond rocks in the Little Bay de Noquette, described a number of fossils from the upper portion of the section and suggested faunal correlation, particularly with the Ohio valley area.

More recently Hussey has published a paper entitled "The Richmond Formation of Michigan"[50] in which the paleontology and stratigraphy are fully discussed. The Michigan section is divided into several units, the lowermost being called the "Bill's Creek beds". The upper part of these Bill's Creek beds are definitely correlated with the Maquoketa, but it is stated that the lower part may not belong to the Richmond.

Previous to the appearance of Hussey's paper, the writer made a short field trip to northern Michigan, chiefly for the purpose of studying the contact between the Maquoketa-like shales and the underlying rocks. Time being limited, only the lower part of the Richmond section was examined. The following observations are presented in chronological order.

The main highway (state road 12) leading east from the town of Rapid River at the head of Little Bay de Noquette crosses Rapid river near the town limits (see fig. 71). Thin beds of crinoidal limestone are exposed in the stream bed for a considerable distance. The rocks are highly fossiliferous at certain horizons; large gastropods and echinodermal fragments predominate though molluscoids are not uncommon. Foerste states that these rocks form the top of the Black River.* No younger beds outcrop at this point. Continuing eastward on M 12 Whitefish river is crossed in less than a mile. Beyond the crossing a secondary road leads north about two miles to Bill's creek, crossing the stream about half a mile above its junction with the Whitefish. Blue shale has been used as road material on both sides of the valley wall. The material is a hard, level-bedded, chocolate-colored shale, weathering to bluish gray. Split slabs show graptolite films and well preserved specimens of *Lingula changi* Hussey. One limy slab covered with bryozoa was found also. Careful searching in the immediate vicinity showed no shale in place.

* Foerste, Aug. F., Written communication, June 6, 1925.

Black River rock is exposed in the bed of the Whitefish at the mouth of Bill's creek. Near its mouth the latter stream flows across a well developed terrace which may be due to the presence of the more resistant Black River rocks. A short distance upstream from the point where the road crosses Bill's creek, soft, well-bedded, reddish clays and shales are in place, probably representing a Pleistocene lake deposit.

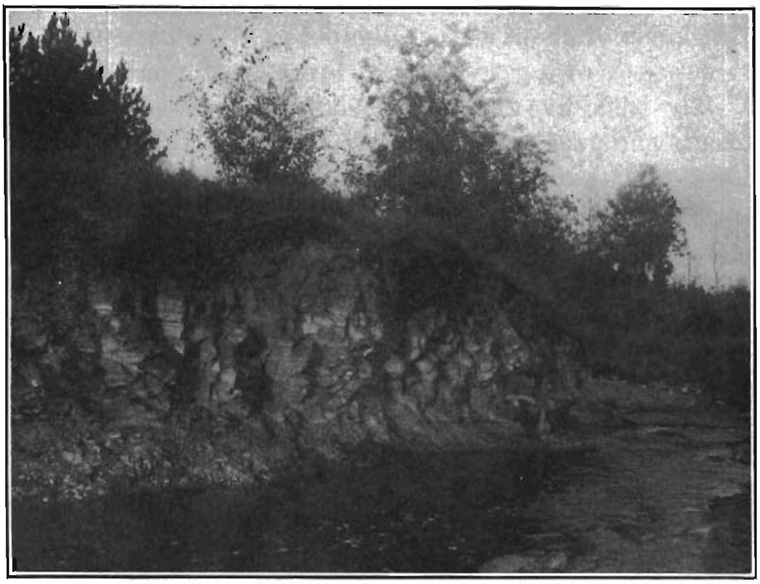

FIG. 72.—Maquoketa section on Bill's creek; base of the exposed section. Upper Peninsula of Michigan.

North about five miles from Bill's creek the road crosses Haymeadow creek (blue shale is encountered at several places along the road *en route* but none of it seems to be in place). Here the shale is in place both above and below the road crossing (Fig. 71, locality 2). Downstream toward the Whitefish the terrace appears and exposures cease, the creek bottom being covered with reworked clay, etc., and the base of the shale is not to be seen. Due west the Black River rock is exposed in the bed of the Whitefish but no shale could be found above it.

Black River rocks are exposed for some distance below a beaver dam in Whitefish river about fifteen miles above its mouth. No contact with the shales is exposed though the latter are found in place five to ten feet above the limestone on the left bank of the Whitefish at a waterhole. The shales resemble the material seen previously and bear graptolites.

Returning to Bill's creek, a road was followed which leads northeast along the top of the right valley wall. After a little over two miles the road crosses the creek (Fig. 71, locality 3). Shale is exposed for about one-fourth mile upstream and three-fourths mile downstream. This is the place from which the road material was obtained. The rocks are nearly horizontal and a total thickness of about 60 feet is exposed. The base of the shales is not exposed owing to the overlapping of younger red lake clays. The basal five feet of the shale exposure contains numerous fossils and greatly resembles the Maquoketa as developed in certain of the Iowa localities. From the collections made the following were identified by comparing with Iowa material:

Glossograptus sp.
Lingula changi Hussey
Dalmanella sp.
Ctenodonta fecunda (Hall)
Bellerophon patersoni Hall
Pleurotomaria (Lophospira) depauperata ? (Hall)
Hormotoma sp.
Liospira micula ? (Hall)
Coleolus sp.
Orthoceras sociale Hall
Isotelus cf. I. iowensis (Owen)
Drepanodus acinaciformis n.s.

Two species in the list, *Lingula changi* Hussey and *Drepanodus acinaciformis* n.s., are especially significant for both are index fossils of the basal Maquoketa. They occur in the type locality in Iowa and in many other localities at the same horizon. The balance of the assemblage likewise suggests the basal Maquoketa of Iowa. The occurrence of *Clidophorus neglectus* Hall, a species not collected by the writer but reported by Hussey and others, also is significant, for this is one of the most characteristic species in the Maquoketa of the middle west. To be sure there are minor faunal and lithologic differences but such are to be expected in areas so widely separated. Thus, many of the common Iowa species are absent and species not found in Iowa are present, but in the writer's opinion these differences total less than the differences existing between certain sections in different parts of the Iowa belt.

The writer does not believe that the above assemblage represents the true Depauperate zone but rather an upward continuation of it (as at Graf in Iowa). It is conceivable that the Depauperate zone will be found later where it seems to belong—in the basal few inches of the shale (in Michigan directly over the uppermost layers of the Black River limestone). An auger might reach it at a favorable place (e. g. the waterhole on the Whitefish mentioned above). It seems possible, therefore, to correlate the lower portion of the Bill's Creek beds with the basal Maquoketa of the Upper Mississippi valley.

Collections were made also from the railroad cut west of the town of Ensign. This cut is located about three miles east and one and a half miles south of the town of Rapid River. Only a few feet of rock are exposed in place but piles of weathered excavated material yielded many forms. At the bottom is found shale like that exposed near the top of the Bill's Creek section above which the rocks are more limy and indurated. In these latter beds (upper Bill's Creek beds of Hussey) bryozoa predominate but trilobites are present in some abundance, with a few brachiopods and pelecypods. The collections made have not been carefully studied by the writer but the zone does not seem to have an exact equivalent in Iowa.

FIG. 73.—Maquoketa shale in the cut east of Ensign, Upper Peninsula of Michigan.

With the Richmond of the Ohio Valley.—Sufficient evidence is not available at the present time to establish an exact and entirely satisfactory correlation between the Maquoketa of the Mississippi valley and the Richmond of the type localities in the Ohio valley. Several correlations, however, have been suggested, as follows:

In 1911, Ulrich (131, Pl. 28) correlated the Arnheim of the Ohio valley (lowest Richmond in that area) with the lower portion of the Wykoff limestone* of the Mississippi valley (Minnesota). The Elkhorn, highest Richmond in the Ohio valley, is correlated with the lower portion of the Brainard shale, youngest member of the Maquoketa.

This same correlation appeared in Bassler's "Index" which was published four years later.(3)

In 1923, Ulrich and Bassler(140) placed the Maquoketa between the Liberty and Whitewater members of the Ohio valley Richmond.

In a later paper by Ulrich (136, p. 82) the Arnheim is placed below the Maquoketa, the Fernvale limestone intervening. This same relation is maintained in his last paper on the subject (138, p. 329). In 1924, Savage published a paper dealing with the Richmond rocks of Iowa and Illinois.(103) He stated that the fauna of the uppermost Maquoketa (Cornulites zone) was of the same age as the Waynesville of the Ohio valley. He also stated the belief that the Fernvale limestone of Illinois was formed at the same time. He then postulated a Fernvale-Upper Maquoketa sea which advanced from the south during lower and middle Waynesville time. The writer believes that it is erroneous to correlate the Fernvale with the uppermost Maquoketa, because in stratigraphic position these two horizons are separated by about 200 feet of shale, at the base of which is found the Depauperate fauna. In the southern part of the Maquoketa basin this fauna *overlies* the Fernvale while in Iowa it *underlies* the Cornulites zone by nearly 200 feet.

Doctor W. H. Shideler first suggested to the writer the possibility of correlating the Depauperate fauna of the basal Maquoketa with a somewhat similar zone which exists near the top of the Arnheim, the basal member of the Richmond across the north

* In the terminology of the present paper the lower Wykoff of Minnesota is recognized as the equivalent of the Elgin member of the Maquoketa of Iowa.

end of the Cincinnati arch.* Shideler has identified the following forms from the Arnheim:

Cornulites n.s.
Dalmanella sp.
Zygospira modesta Hall
Ctenodonta sp.
Clidophorus faberi Miller
Clidophorus fabula (Hall)
Microceras inornatum Hall
Cyclora depressa Ulrich
Cyclora hoffmanni Miller
Cyclora minuta Hall
Cyclora parvula (Hall)
Hyolithes parviusculus (Hall) (same as Hyolithes versaillesensis Miller and Faber ?)
Coleolus iowensis James (Hyolithes ? dubius Miller and Faber)

This assemblage suggests the Depauperate fauna of the Maquoketa but, as Shideler points out, similar but "patchy" occurrences, "chiefly of *Hyolithes, Cyclora, Microceras,* and *Ctenodonta* are locally developed. . . . . . . in the Mt. Auburn, the Corryville, the Mt. Hope, and down as far as the Mohawkian in Kentucky".† This weakens the strength of the correlation somewhat. It must also be pointed out that the Fernvale, which underlies the Maquoketa in parts of the Mississippi valley, overlaps the Arnheim in Tennessee (131, p. 422). In avoiding this difficulty Shideler suggests that "possibly the Tennessee Fernvale occurs above the Arnheim proper but beneath the disturbed Cyclora limestones which we have regarded as topping the Arnheim."† In any event the suggested correlation is not entirely satisfactory at the present time.

It seems highly probable that the Brainard shale at the top of the Maquoketa (and its equivalent in the Southeast Area) is to be correlated with the Elkhorn, youngest member of the Ohio valley Richmond. Strong evidence supporting this belief has come to light as a result of Shideler's work with the bryozoa. Thus the following species which occur in the Cornulites zone of the Maquoketa also are common in the Elkhorn of the Cincinnati province.§

Diploclema varians Shideler n.s.
Anaphragma mirabile Ulrich
Helopora elegans Ulrich
Sceptropora facula Ulrich
Dicranopora fragilis (Billings)

In addition to the above diagnostic species there are thirteen other bryozoa common to the uppermost Maquoketa and the Elk-

* Shideler, W. H., verbal communication, 1924.

† Shideler, W. H., written communication, February 4, 1927.

§ Some of them are found also in the Whitewater, which lies just below the Elkhorn.

horn, but these are wide ranging Richmond species and their occurrence is of little or no significance.

Valuable evidence, however, is forthcoming from the ostracodes. *Tetradella quadrilirata* (Hall and Whitfield) and *T. simplex* (Ulrich) occur in the Cornulites zone of the Maquoketa. These are species that range in the Ohio valley area from the Liberty through the Whitewater and Elkhorn. Likewise *Beyrichia parallela* (Ulrich), which occurs in the Cornulites zone, has been reported from the Upper Whitewater of Ohio and Indiana and from the Middle and Lower Elkhorn at Hamburg, Indiana.

There seems to be no evidence at present that would tend to discredit a correlation between the Cornulites zone of the Maquoketa and the Elkhorn of the Ohio valley area.

Shideler has also pointed out that the Cornulites zone of the Maquoketa is very clearly a recurrence of the Fernvale, a number of the bryozoans and brachiopods being common to both.* This would suggest that the Fernvale and the Maquoketa are quite close in time, but Ulrich states† that near Nashville, Tennessee, the Fernvale occurs *beneath the Waynesville,* which would indicate a considerable time interval between the Fernvale and the Cornulites zone. Of course, if the suggested correlation (p. 368) between the Depauperate zone of the Maquoketa and the top of the Arnheim be correct, the Fernvale must be very much older than the Cornulites zone, because the Arnheim lies beneath the Waynesville in the Ohio valley area.

It would seem that the key to the perplexing problem of the exact age of the Maquoketa faunas lies in the Fernvale and the other pre-Maquoketa Richmond rocks of the Mississippi valley area. When these rocks have been studied more carefully we shall understand the Maquoketa more perfectly.

Paleontology

FAUNAL ZONES

There are a number of distinct faunal zones in the Maquoketa shale, some of which sharply mark definite horizons and persist throughout the entire Iowa belt, while others have a more general vertical distribution and are limited entirely either to the

* Shideler, W. H., oral communication, March 24, 1928.
† Ulrich, E. O., verbal communication.

northwest or to the southeast areas. Thus there are two fossiliferous zones that are characteristic of the Maquoketa in both areas, one at the base, the Depauperate zone, and one at the top, the Cornulites zone. A third, the Graptolite zone, might be added. The last named is widespread as regards horizontal distribution and it appears to be limited entirely to the Elgin member and its equivalents, but it is not as exact a marker as are the two previously mentioned.

In a second group may be placed (1) the *Isotelus* beds, which are so characteristic of the lower Elgin in the northwest, (2) the *Vogdesia* beds, which overlie the last in many places but which show a less general areal distribution, and (3) the Upper Elgin fauna, which occurs widely in the northwest area.

Overlying the Elgin is the Clermont shale member. Fossils rarely aid in the recognition of the Clermont because, like the Brainard, which it resembles lithologically, it is frequently barren. Locally weathered outcrops yield large faunas but these seem to contain no good index fossils. However, since the Clermont is a thin member, the Elgin below or the Fort Atkinson above can usually be found.

The fauna of the Fort Atkinson member contains several fairly good index fossils, among the best being a brown-shelled *Lingula beltrami* and the peg-coral, *Lindströmia solearis* n.s. A number of echinoderms are typical in that they occur in no other member, but they are rather too rare for general use.

The Brainard shale is practically barren except for the Cornulites zone mentioned above.

In the southeast area, in addition to the zone already given, there are poorly preserved remains at certain levels but as yet these are too imperfectly known to be of use in stratigraphic work.

THE DEPAUPERATE ZONE

The assemblage of small fossils occurring in such abundance in the lowermost strata of the Maquoketa has long been known to local geologists as the *Depauperate fauna.* However, this term seems never to have been precisely defined in exactly this connection and consequently several meanings are attributed to it. Most students seem to make no distinction between the terms "depauperate fauna" and "dwarf fauna". Both have been applied to the Maquoketa. Since the basal Maquoketa fauna can be shown to differ from a true dwarf fauna it is proposed so to define the term *depauperate* that it will apply as a descriptive term to such an unique fauna as the one under consideration and at the same time differentiate such an assemblage from true dwarf faunas, accounts of which have appeared in the literature from time to time and to which reference will be made shortly. As thus defined a depauperate fauna is one in which the *great bulk of the species is composed of individuals which are distinctly (but not abnormally) small, yet abundant and diversified.* Such a definition excludes (1) the *normal fauna* which contains a fair proportion of large and medium sized species, and (2) the *dwarf fauna* which is composed entirely of *dwarfs of normally larger individuals.* A series of illustrations may serve to make the distinction clearer.

(1) *Normal fauna.*—The fauna of the uppermost Maquoketa beds will serve as a good example of a normal fauna. The forms show great range in size and make up the type of fauna one would expect to find in shallow seas today. Thus some of the species (many of the mollusca and some of the brachiopods and trilobites) measure over an inch in greatest diameter; many others are exceedingly small; in between these two groups are many species of moderate size. Arranging all adult forms in a series according to size one would have a more or less uniform gradation from the smallest species to the largest.

(2) *Dwarf fauna.*—An excellent example of this type of fauna has been described by Loomis from the Devonian of New York.* Here is a diversified fauna of 51 species, most of which are less than 2 mm. in diameter. It is not a fauna of embryos but one of *dwarfs,* stunted adults of species reaching much larger size elsewhere.

(3) *Depauperate fauna.*—The basal Maquoketa fauna, as known at present, is composed of 44 species which, with a few exceptions, do not exceed a quarter of an inch in diameter. This is surely unusual and suggests dwarfing but *so far as is known* the Maquoketa specimens are not dwarfs but make up a group of small animals none of which *ever grew any larger.* However,

* See footnote, page 407.

many of the species are smaller than the average of their respective genera.

It should be pointed out that universal *smallness* in a fauna is unusual, be it true dwarfing or not. Biologists can tell us of no modern fauna made up of a large number of species, representing all important invertebrate groups, in which the average size is anywhere near as small as that of certain Paleozoic faunas. However, the subject is not always a mysterious one. Some of the causes giving rise to dwarf faunas (and perhaps to depauperate faunas) will be discussed later. The term Depauperate is applied to fit the observed facts and to answer the objections of those who state truthfully enough that the basal Maquoketa fauna is not one of dwarfs, at least not so far as is known.*

It is proposed, therefore, to name the basal horizon of the Maquoketa the Depauperate zone, making it as such, purely a faunal zone and not a formation member. Thus it is a part of the Elgin member in the Northwest Area and forms the base of the southeast section, where the formation can not be divided into members. From time to time other (and in some cases what appear to be less appropriate) descriptive terms have been applied to the zone. Most of the earlier workers who recognized the existence of the formation at all noted this horizon. Many of these have already been mentioned in the Historical Sketch and need not be repeated here. Daniels' description of this zone, which formed the lower part of his "Nucula shale," is of interest and is quoted below:

"The lower portions, however, are wonderfully rich in petrifactions preserved in the highest perfection. The entire rock is often a mass of fossils, with barely enough of some cement to hold them together. These fossils are mainly shells. Among them we find abundantly *pleurotomaria, endoceras, modilopsis, nuculaformis, clidopherous-planulatus, nucula-poststriata, lingula,* with a few *trilobites* and other fossils unknown.

"It is a singular fact, that all these fossils are exceedingly minute as compared with those of similar types, found in the rocks below. The huge chambered shells of the lower limestones, measuring often six feet in length and two feet in diameter, are here represented by forms rarely exceeding four inches in length, and

* It is true that a large number of the fossils from this horizon are embryonic forms. These are very minute but are not true dwarfs since the adults occur with them. The *universal smallness* referred to is the smallness of the adults, not of the young specimens.

one inch in diameter. The *nucula* of the gray limestone is often two inches in length, while that of the shale is only one-third of an inch long. A similar diminution seems to have affected every form of life; constituting as it were, a fossil Lilliput, analagous to what Hugh Miller has described as the "age of dwarfs", among the fishes of the old red sandstone.

"This deposit extends across the Mississippi into Iowa, and south into Illinois. It offers to the naturalist a new field of investigation, replete with interest and instruction. In this brief notice I can barely call attention to the fact of its existence, but hope at some future time to present a fuller account of it and its wonderful fossils. I have called it for the present the "nucula shale", from the great numbers of this fossil which it contains."(24)

Daniels' "Nucula shale" was also mentioned by other workers.(85) (45) Later the forms referred to *Nucula* were placed in the genus *Ctenodonta* and Calvin and Bain in discussing the section of Dubuque county, Iowa, state that, "The lowest member of the Maquoketa formation may very properly be called the Ctenodonta bed" (14, p. 422). This usage of the term "Ctendonta bed" is unfortunate and should be discarded, for Winchell and Ulrich (165, p.xcvi) have a prior claim, having applied the term to a horizon in the "Black River group" (Galena) of Minnesota several years before.

In the meantime Sardeson (93, vol. 19, p. 31) had included this zone in his "Diplograptus bed", thinking that the fossils of the Depauperate zone were "secondary fossils" which "must have come a long distance from where local conditions had produced a difference of fauna." Sardeson's term, therefore, really refers to the Graptolite zone overlying the Depauperate zone and usually distinctly different both lithologically and faunally.

Finally the term "Lamellibranch zone" was applied by Trowbridge and Shaw to the horizon as developed in Jo Daviess county, Illinois (122, p. 67). The writer believes that this term also should be discarded since the lamellibranchs are not always abundant and since the term "Lamellibranchiata" has been dropped by most zoologists, who prefer "Pelecypoda", a term whose ending agrees with the names of the other classes of the mollusca.

It is true that the pelecypods are usually quite abundant, but if one were to name the zone by its most characteristic fossil, that one would have to be *Orthoceras sociale* because it is always present in abundance and is the largest species in the fauna. However, since *Orthoceras sociale* is the species from which the "Orthoceras beds" of the classic Graf section take their names, this term can not well be used. It seems to the writer that the term "Depauperate zone" as here employed is entirely appropriate and may be applied to the basal horizon of the Maquoketa over the entire Mississippi basin.

Stratigraphic Position and Detailed Sections.—The thin Depauperate zone is an ideal one for the stratigrapher. Its lithologic and faunal characteristics are unique and it is invariably found at the base of the formation. Its fossils are known from the entire area in which the Maquoketa outcrops and this zone should be looked for in well borings outside the area, for its fossils are minute and could be preserved even in finely ground material. Frequently in known outcrops erosion has removed the soft basal shales and the overlying material has slumped over the dolomite below, but where the contact of the two formations is well exposed, in narrow gullies with high gradients, the depauperate zone can be found with little difficulty. This persistence of the zone is a feature which earlier workers in Iowa entirely overlooked. In fact the county reports point out again and again the range in character of the basal Maquoketa, both lithologically and faunally. These statements are not true as regards the fauna of the Depauperate zone, which shows only slight changes from northern Iowa to Arkansas.

Plate XVII shows the known distribution of the fauna and the 18 locations where it has been found. Three of these localities were not visited by the writer but he had the opportunity of studying material collected from them by E. O. Ulrich. Of the fifteen localities visited, eleven are in Iowa, three in Illinois, and one in Missouri. The exposures which were visited are described in detail below, beginning in the northern part of the area.

(1) *Springfield Township, Winneshiek County, Iowa.*—Four miles south of the city of Decorah the "Galena" limestone is exposed for a considerable distance in a steep tributary gully in the right bank of Trout creek (northeast quarter of section 18). The

actual contact with the Maquoketa is not exposed but digging reveals the Depauperate zone, here only one inch in thickness.

3. Yellow indurated shale. Regularly bedded but irregularly jointed. Beds several inches in thickness. Barren so far as observed. Several feet thick.
2. Depauperate zone. Slightly calcareous clay stained various shades of yellow and brown; phosphatic and containing some pyrite and much limonite, the limonite probably weathered from pyrite. White pebbles of phosphatic limestone present. "Minute pellets" abundant. Associated with the latter were found nine fossils of the Depauperate fauna. For this and similar lists see distribution table, page 384. One inch, more or less.
1. Uppermost layer of "Galena." Light gray limestone containing an abundance of small crinoid stem segments. The surface of the topmost bed is stained to a dark brown and shows a glistening surface. Ten feet, plus.

(2) *Clermont Township, Fayette County, Iowa.*—Near the line separating sections 21 and 28, on the right bank of the stream which joins Turkey river in the last named section, the upper layers of the "Galena" outcrop on the steep valley wall. As measured in a narrow side gully the top of the formation is sixteen and one-half feet above the creek. Here again slumping of the soft Maquoketa has obscured actual contact with the "Galena", but digging in the bed of the creek reveals the Depauperate zone with a thickness of two and one-half inches.

		Feet	Inches
5.	Greenish gray plastic clay. Very calcareous but not phosphatic. Barren as far as observed. Grading above into soil		8+
4.	Yellow shale. Well bedded, layers measuring several inches in thickness. Very calcareous but not phosphatic. Apparently barren		10
3.	Yellow to brown highly ferruginous clay. Slightly calcareous, phosphatic, and contains material at base similar to No. 2. Pellets abundant and associated with them are ten of the common fossils of the Depauperate fauna		2½
2.	Gray shale, slightly indurated and irregularly bedded. Slightly calcareous, quite phosphatic and contains a little limonite. Gray pebbles of phosphatic limestone showing an irregular but smoothed surface are present. Minute pellets and fossils abundant in irregular masses, being held together by a light colored calcareous cement. Eighteen typical Depauperate fossils identified		3½
1.	Uppermost layers of "Galena." Light gray phosphatic limestone	16	5

(3) *Marion Township, Clayton County, Iowa.*—In the northwest quarter of the southeast quarter of section 19 the top of the "Galena" appears in the bed of a north flowing tributary of Turkey river. At one point the stream has undercut its left bank exposing several feet of basal Maquoketa. The Depauperate zone is over seven inches in thickness at this point.

	Inches
6. Bluish shaly limestone, weathered brown along bedding and joint cracks. Well marked beds several inches in thickness. Slightly phosphatic. Barren at base but grades above into typical Isotelus beds. Several feet thick.	
5. Chocolate brown shale in thin regular beds. Soft, noncalcareous and slightly phosphatic. A few specimens of *Leptobolus occidentalis*	7
4. Similar to No. 3 but more highly ferruginous. Phosphatic and slightly calcareous. Contains ten typical fossils of Depauperate zone	1¾
3. Dark gray, poorly bedded shale. Phosphatic and slightly calcareous. No pyrite and very little limonitic material. Minute pellets very numerous. Occasional layers show the "polish" exhibited by pebbles in other localities. Ten fossils of the Depauperate zone identified	1½
2. Weathered, somewhat calcareous clay ranging in color through all shades of gray, yellow and brown. Concentrations of dark colored pellets and fossils in pockets. Phosphatic. A few polished pebble-like nodules. Fossils abundant, fifteen typical Depauperate species	4
1. Uppermost beds of "Galena" formation.	

(4) *Sperry Township, Clayton County, Iowa.*—A trifle south of the center of section 11 a small tributary of Deep creek exposes crinoidal layers of the upper "Galena." The Depauperate zone here totals eleven and one-quarter inches in thickness, showing again its tendency to become progressively thicker from north to south in this area.

	Inches
5. Yellow and gray clay and shale. Calcareous but not phosphatic. Barren as far as observed. Partly slumped, grading into soil above	12+
4. Light brown shale, calcareous and phosphatic. Concretions of limonite an inch in diameter not uncommon. Minute pellets exceedingly abundant, fossils also, especially the ostracodes. Ten species of the Depauperate fauna	2½–5
3. Light brown argillaceous phosphatic limestone. No limonite but specks of turgite. Pellets and fossils concentrated in lowest one-half inch. Upper 1¼ inches barren. The fauna includes nine species	1¾
2. Light to dark gray argillaceous limestone. Indurated but poorly bedded. Phosphatic; bits of turgite, shows polished surface occasionally. Pellets and fossils locally abundant. Slumping obscures characteristics. Fifteen species identified	7
1. "Galena" limestone, gray crinoidal layers containing much calcite.	

(5) *Elk Township, Clayton County, Iowa.*—In the southwest quarter of section 23 the upper "Galena" and basal Maquoketa are both well exposed on the right bank of Elk creek. The Depauperate zone measures fourteen inches in thickness.

		Feet	Inches
6.	Similar to No. 5 but in beds several inches in thickness. Contains abundant pyrite in minute grains. Apparently barren	1	8
5.	Gritty brown shale, slightly calcareous and phosphatic. In thin beds. One specimen of *Orthoceras sociale* ?	1	3
4.	Chocolate brown thinly bedded shale. Jointing irregular. Weathers to a light bluish gray. Calcareous, phosphatic, and containing many well developed pyrite crystals. *Leptobolus occidentalis* and *Diplograptus peosta* abundant	7	7
3.	Similar to No. 2 but containing much more pyrite, some of which is in large crystals. Bits of turgite also present. Fossils include eleven typical species		1
2.	Dark gray to black slightly indurated shale. Bedding and jointing irregular. Phosphatic and slightly calcareous. Layers range in thickness from a fraction of an inch to slightly over an inch. Contains small amounts of pyrite, limonite and turgite. Fossils exceedingly abundant but not evenly distributed. Thirteen species identified		13
1.	Uppermost beds of "Galena" formation.		

(6) *Center Township, Dubuque County, Iowa.*—One-fourth of a mile north of Graf a small creek is crossed by the Graf-Twin Springs road. This creek joins the Little Maquoketa from the west. A short distance upstream from the point at which the road crosses the stream the "Galena"-Maquoketa contact is well exposed in the right bank. The Depauperate zone is here twenty-three inches in thickness.

		Inches
10.	Thinly bedded shales similar to No. 7. Poorly preserved graptolites and *Lingula changi* Hussey. Grading into soil above	22
9.	Yellowish brown clay and shale. Only slightly plastic. Weathers into irregular blocks	3
8.	Chocolate brown laminated shale. Noncalcareous and showing but a trace of phosphate. Graptolite films and *Leptobolus occidentalis*	3½
7.	Brown arenaceous layer. Many specimens of *Leptobolus occidentalis* and a few other fossils	2
6.	Light brown laminated shale. Few fossils	1
5.	Soft brown plastic clay. Few fossils	2
4.	Gray to black poorly bedded shales. Phosphatic and slightly calcareous. Smooth gray noncalcareous pebbles present. Fossils abundant, seventeen species	7
3.	Soft limonitic layer. Phosphatic and slightly calcareous. Pellets abundant. A few fossils, five species	2
2.	Gray poorly bedded shale. Phosphatic and slightly calcareous. Highly mineralized, much crystalline pyrite which occasionally encloses masses of black sphalerite; some crystalline calcite. Smooth noncalcareous pebbles abundant. Fossils very abundant but irregularly distributed. Pockets of light gray barren shale. Fifteen species identified	9
1.	Uppermost "Galena" exposed in creek bed.	

(7) *Julien Township, Dubuque County, Iowa.*—On north 14th Street in the city of Dubuque there is an abandoned quarry in which the upper beds of the "Galena" are exposed. Careful searching along the top of the quarry face yields many of the

larger fossils of the Depauperate zone and bits of the enclosing rock though the beds themselves are not actually seen in place. The rock is a phosphatic and slightly calcareous gray shale of the usual sort. Fourteen typical Depauperate fossils were collected.

(8) *Prairie Spring Township, Jackson County, Iowa.*—At the small town of St. Donatus in Tete de Mort township, Mort creek is joined by a tributary from the northwest. The Depauperate fauna can be located by following this creek to the center of section 1 of Prairie Spring township. The upper beds of the "Galena" form a low escarpment along the right bank of the creek. This is penetrated at intervals by short gullies. In one of these, 1.6 miles northwest of St. Donatus, the Depauperate zone is exposed 31½ feet above the main creek. The actual contact of the shales with the underlying "Galena" is not exposed, but Maquoketa is in place two feet above the highest "Galena" slabs. The brownish clay of the typical Depauperate zone contains abundant fossils, belonging to twenty species. They are not so abundant in the yellowish green clay above.

(9) *Tete de Mort Township, Jackson County, Iowa.*—In sections 13 and 14 of Tete de Mort township a small unnamed creek flows east to join Mississippi river. Close to the line between the two sections this creek receives a small northward flowing tributary. The gully of this tributary is steep sided and rocky in its lower part because the "Galena" is exposed. Above the "Galena" the basal Maquoketa comes in and the Depauperate zone can be found in the gully itself and in a small lateral tributary from the east. The fossils are enclosed in a soft, much weathered brown shale. This zone totals less than six inches in thickness. Above lies plastic blue clay which contains no fossils as far as observed.

(10) *Bellevue Township, Jackson County, Iowa.*—Just south of the town of Bellevue, Mill creek joins Mississippi river from the west. Immediately above this juncture the uppermost beds of the "Galena" dolomite are exposed in the bed of the creek. About two hundred yards west of the point at which the road leading south from Bellevue crosses Mill creek, the lower beds of the Maquoketa appear above the "Galena" in the right bank of the creek.

The unweathered beds of the Depauperate zone are well exposed at the creek edge. The lower four inches is made up of hard gray shaly layers and contains relatively few fossils. The next six inches is softer and almost black in color. These beds are highly fossiliferous and contain much pyrite. Above these layers are four inches of soft gray shales which are practically barren. Slumping obscures the remainder of the section at this point, the thin gray and brown shales of the talus being barren.

(11) *Hanover Township, Jo Daviess County, Illinois.*—On the right bank of Apple river, immediately below the dam at Hanover, the "Galena"-Maquoketa contact is fairly well exposed. Trowbridge and Shaw have reported the following:

"At the dam at Hanover massive dolomite is overlain by three feet of talus and wash, and three feet of thin-bedded, fine-grained, arenaceous, chocolate colored clay shales. containing egg-shaped nodular masses of clay. Six and one-half feet above the top of the Galena is a six inch layer of open, porous, but resistant rock, made up largely of shells of pelecypods, gastropods, and a few large brachiopods of the genus *Lingula.*" (122, p. 67.)

The above outcrop was not very well exposed at the time of the writer's visit. Several feet of "Galena" was exposed in place below the dam, above which were found loose pieces of Maquoketa rock. This was a gray to brown slightly indurated, slightly calcareous shale containing Depauperate fossils distributed irregularly through the rock in stringers. Other fragments of rock were made up almost entirely of the "egg-shaped nodular masses of clay" measuring 10 to 12 mm. in diameter. These were embedded in a matrix composed chiefly of the small fossils and the minute pellets so that the rock resembled a conglomerate. Both fossils and rock were phosphatic and slightly calcareous.

Only a little material was collected by the writer but a large collection for study was loaned by Mr. T. D. Shipton of Hanover. This includes twelve of the typical Depauperate fossils. Mr. Shipton reports that these may be found in great abundance at time of low water.

(12). *Pleasant Valley Township, Jo Daviess County, Illinois.*—The following section of the lower Maquoketa is given by Trowbridge and Shaw (122, pp. 63, 64) as occurring in the wall of Plum river valley half a mile southeast of the village:

	Feet	Inches
"Clay shale, dark gray, chocolate colored, uniform, breaks in flattish bits with conchoidal fracture	8	
No outcrop	10	3
Thin beds, black, loose, soft, porous, contain pelecypods, phosphatic pellets, gastropods, and orthocera at base."		

The lowest beds described above were not found in place by the writer owing to the fact that the river was in flood stage, but slabs showing the typical fossils were abundant in the stream bed at about the top of the "Galena." These slabs are quite carbonaceous, slightly calcareous, and highly phosphatic. They resemble the Bellevue material but seem to contain more fossils and less pyrite. They yielded twenty-one species of fossils.

Number 3 of the above section outcrops above for some distance at the water's edge. These shales are noncalcareous but slightly phosphatic. A few graptolites and other doubtful species were found.

(13) *Pike County, Missouri.*—In the center of section 15, township 54 north, range 3 west, the north-south road crosses a small creek. By walking downstream 330 paces from this point outcrops of the contact zone may be seen in the floor of the creek and in the left bank. The following section is exposed:

	Feet	Inches
6. Paper-thin shales with interbedded hard layers up to 4 inches in thickness. Barren as far as observed	3+	
5. Limestones, slightly phosphatic, with large pyrite crystals. Shows "cone-in-cone" structure in section. Bedding planes show botryoidal structure with swellings downward		1
4. Paper-thin shale parting. Barren		1—
3. Conglomeratic limestone with some pyrite. Seven typical fossils of the Depauperate fauna		1±
2. McCune limestone.* Contains much pyrite in irregular veins and clusters of crystals, also much crystalline calcite and sphalerite. Hundreds of large cephalopods pave the creek floor. Mostly straight forms		3
1. McCune limestone. Shows cavernous weathering.		

A similar section is exposed 105 paces upstream in the right bank of the creek. Here the Depauperate zone, containing 12 typical species, is overlain by several feet of clay shales, yellow at base and blue-green above.

(14) *Calhoun County, Illinois.*—About one mile south of Batchtown the basal Maquoketa is exposed in the right bank of

* Bradley, John H., Jr., Verbal communication, December, 1925.
In his paper, The Stratigraphy of the Kimmswick Limestone of Missouri and Illinois: Jour. Geol., 35, No. 1, p. 62; 1925, the McCune limestone is "provisionally included with the Kimmswick."

Madison creek a short distance upstream from the point where the Batchtown-ferry road crosses the creek. This outcrop has been carefully described by Weller.(147) The following section, which agrees with that given by Weller, was seen by the writer:

		INCHES
5.	Slightly calcareous shale of varying hardness in even beds. Contains *Diplograptus*? sp. and *Leptobolus occidentalis*. Several feet.	
4.	Yellow and green plastic shale. Finely laminated. Some beds slightly indurated. Calcareous and slightly phosphatic.	
3.	Soft shaly material containing minute pellets. Slightly calcareous and highly phosphatic. Many pebbles, some of which are of chert. Depauperate fossils very abundant, 21 species identified	1±
2.	Red limonitic residual (?) clay containing irregular fossiliferous cherts. Slightly calcareous and phosphatic. Fossil fragments are abundant but differ greatly from those of the overlying beds. One specimen of *Leptobolus occidentalis?* and one minute specimen of *Pleurotomaria depauperata?* The identifications are doubtful and the specimens not certainly in place. A great variety of crinoidal material is present. This includes stem segments of a number of unusual types, several body plates and one base. Most of these are of white calcite, others are limonitic and dissolve but slightly in hydrochloric acid. Fragments of silicified brachiopods of at least two species (one a *Plectambonites*) occur	4+
1.	Kimmswick limestone, exposed in the bed of the creek. Upper surface irregular under the overlying material. Typical fossils.	

Number two of the above section is a pre-Maquoketa residual clay according to Weller.(147) This is possible, in which case the silicified brachiopods probably came from the cherts. But what of the calcareous crinoidal material? If these fossils are pre-Maquoketa in age how could they have resisted solution during the leaching of the residual clay? They certainly *do not* resemble basal Maquoketa material either in form or in mode of preservation. Later identifications may throw some light on the interpretation of this deposit, which at the present writing seems rather an enigma.

The "Galena"-Maquoketa Contact in Allamakee County.—As one travels north from Postville along the road which separates section 28 from section 29, Post township, a number of outcrops of the lower part of the Maquoketa are encountered. In the southeast quarter of section 16 a small gully crosses the road from east to west. A short distance east of the road a tributary gully enters from the north. Digging in the bed of this tributary a few yards above its mouth reveals an irregular limonitic band whose appearance is immediately suggestive of the Depauperate zone though no large fossils may be seen. As found in the field the material is considerably mixed with glacial sand and soil. The large smooth pebbles and minute pellets are very numerous. No good section can be made though the "Galena" can be found in place below it. Washing of a sack of the material yielded the following fossils in their usual abundance:

Hindia parva ?
Diplograptus peosta ?
Leptobolus occidentalis
Acrothele ? richmondensis n.s.
Ctenodonta cf. C. fecunda
Bellerophon sp.
Pleurotomaria depauperata
Hyolithes parviusculus
Coleolus iowensis
Orthoceras sociale
Ostracoda (undet.)
Priscochiton elongatus n.s.

Five feet above this zone is an outcrop of chocolate brown shale, exposed at a zone of springs which forms a marshy spot in the field. Overlying this is a slump bank of yellowish green shale on which lie the indurated slabs of the Isotelus beds bearing the characteristic fossils.

*Table Showing Fossils Previously Reported from Depauperate Fauna**

	Hall 1862	Whitney 1866	Win. and Ulr. 1897	James 1900	Calvin and Bain 1900	Grant and Burchard 1907	Weller 1907	Trowbridge and Shaw 1915	Savage 1924
1. Hindia parva								x	
2. Lingula sp.	?							x	
3. Dalmanella testudinaria								x	x
4. Zygospira modesta				?				x	x
5. Ctenodonta fecunda	x	x	x	x	x	x	x	x	x
6. Ctenodonta obliqua				x				x	x
7. Clidophorus neglectus	x		x	x	x	x	x	x	x
8. Cyrtolites conradi	x								
9. Bellerophon lirata	x								
10. Bellerophon patersoni	x								
11. Bellerophon sp.									x
12. Pleurotomaria depauperata	x	?		x	x	x		x	x
13. Liospira micula	x			x	x	x		x	x
14. Lophospira sp.									x
15. Hyolithes parviusculus	x			?	x	x		x	
16. Orthoceras sociale				?					x
17. Orthoceras sp.		x	x		x	x	x	x	
TOTAL NO. SPECIES	9	3	3	8	6	6	3	11	10

* Daniels' list (1854) is not included in this table. It consists of seven forms, five of these being generic references only. The two specifically identified seem to be in error (see p. 373 above).

Table Showing Distribution of Fossils of Depauperate Fauna

NAME	Locality Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hindia parva ? Ulrich		x	x	x	x	x	x	x	x	x	x	x		x
Tetradium ontario Hall		x							x					x
Diplograptus peosta Hall		x	x	x	x	x		x		x				x
Serpulites sp.		x	x	x	x	x			x				x	
Lepidocoleus ? sp.										x		x		x
Spatiopora iowensis Ulrich											x			x
Diplotrypa obscura Shideler n.s.							x							
Arthropora shafferi ? Meek		x												
Rhinidictya sp.		x												
Leptobolus occidentalis Hall	x	x	x	x	x	x		x	x	x		x	x	x
Lingula changi Hussey						x		x	x	x		x		
Acrothele ? richmondensis n.s.		x	x	x					x					
Conotreta obliqua n.s.	x				x	x		x	x	x				x
Orbiculoidea sp.									x					
Dalmanella sp.	x		x	x	x	x	x	x	x	x	x	x	x	x
Zygospira sp.										x				
Priscochiton elongatus n.s.		x	x	x	x	x		x	x	x				
Priscochiton sp.								x						
Ctendonta fecunda (Hall)	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ctenodonta obliqua (Hall)					x	x	x		x	x	x	x		
Clidophorus neglectus (Hall)					x	x	x	x	x	x	x	x	x	x
Conocardium sp.														x
Cyrtolites conradi Hall		x				x			x	x		x		
Bellerophon lirata Hall									x		x			x
Bellerophon patersoni Hall		x	x	x		x		x	x	x	x	x	x	x
Pleurotomaria (Lophospira ?) depauperata (Hall)	x	x	x	x	x	x	x	x	x	x		x	x	x
Lophospira sp.							x	x						
Hormotoma sp.			x	x			x		x				x	x
Liospira micula (Hall)		x	x	x		x	x	x	x	x	x	x	x	x
Cyclora sp.								x		x				
Hyolithes parviusculus (Hall)	x	x		x		x	x	x	x	x	x	x	x	x
Coleolus iowensis James	x	x	x	x	x	x	x	x	x	x		x	x	x
Conularia pumila n.s.		x												
Conularia putilla n.s.				x										
Orthoceras sociale Hall	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ephippiorthoceras laddi Foerste n.s.									x					
Kionoceras thomasi Foerste n.s.														x
Kionoceras tenuitectum Foerste n.s.									x					
Beloitoceras whitneyi (Hall)*														
Calymene mammillata Hall							x		x		x	x		
Primitia cf. P. cincinnatiensis (Miller)				x										
Ulrichia bivertex ? (Ulrich)				x										
Bythocypris ? sp.				x										
Drepanodus acinaciformis n.s.	x		x	x	x	x		x	x			x	x	
TOTALS 44	9	18	15	20	14	19	14	19	26	20	12	17	13	20

* From Scales Mound, Illinois. Spec. in U. S. Nat. Mus.

ISOTELUS ZONE AND ITS ASSOCIATED GRAPTOLITES

This zone which, as previously stated, occupies a definite horizon in the lower Elgin, furnishes a great abundance of fossils but relatively few species. The dominant form is *Isotelus iowensis*. In good localities pygidia of this species almost cover the slabs. Cheek spines, fragments of the eyes, glabellæ and hypostomas are less common but not rare. Body segments are not infrequently met with and the lucky collector occasionally discovers a complete specimen. Preservation is excellent, showing even the minute eye facets on many fragments. This is the only horizon where this species occurs in abundance, though rare fragments are found at higher elevations. The writer found one pygidium in the cherty beds of the Fort Atkinson limestone. Associated with *Isotelus iowensis* are other trilobites (*Isotelus rejuvenis, Isotelus maximus, Calymene* sp.), graptolites (frequently in abundance), *Cyrtolites* sp., and fragments of *Cyclendoceras atkinsonense* Foerste n.s., some specimens of the last named measuring over five inches across.

The rocks containing this fauna are unusual. The bedding is remarkably regular and weathered outcrops show flat slabs two or three inches in thickness. These are polygonal in outline with right angle joint faces. The material is a dense shaly limestone and slabs can be easily split parallel to the bedding. These lith-

FIG. 74.—Isotelus beds of the Elgin member. Dover Mills, east central section 26, Dover township, Fayette county, Iowa. Photo by Thomas.

ologic characters are the same over the entire northwest area from Clayton county to Minnesota, but the fossils are most abundant in the area about the towns of Elgin and Clermont.

Apparently these beds have no recognizable equivalent in the Southeast Area. One fragment of a large trilobite showing several body segments and one *Bumastus* pygidium were collected about twenty-five feet above the base of the formation at Bellevue. The first specimen may be an *Isotelus*. Both were associated with graptolites as are the *Isotelus* fossils of the north. Future collecting may yield more satisfactory material.

There seems to be a rather definite graptolite zone in the lower part of the Maquoketa.* It is well developed at many localities in northern Iowa and southern Minnesota and it persists even in the comparatively barren blue shales of the Southeast Area. In the Northwest Area the graptolites (chiefly poorly preserved films of *Diplograptus peosta*) are found associated with and immediately below the abundant fragments of *Isotelus*. This locates them very close to the base of the formation, certainly within ten feet of it in most cases. In Allamakee county a few *Isotelus* slabs bearing graptolites were found seventy-five feet above the "Galena", but it is not certain that these were in place; they may have been carried a considerable distance by road workers.

Locally the graptolite films are very abundant. (See Plate VII.) Elsewhere one may split dozens of promising slabs before finding a fragment while in certain thin horizons they appear to be entirely absent.

At Bellevue in Jackson county and in nearby outcrops graptolies are abundant at levels ranging from twenty to forty feet above the base of the formation. At Graf in Dubuque county they are the dominant fossils of certain beds. In addition they occur sparingly as broken fragments among the small fossils of the Depauperate fauna in both the Northwest and the Southeast Areas.

Thus in summary one may safely say that in the Northwest Area they seem restricted to the lowest twenty feet of the Elgin beds, being most abundant at the base of the *Isotelus* beds and

* This is the "Diplograptus bed" of Sardeson, Amer. Geol., 19, p. 31, 1896. In many localities the forms seem limited to a thin bed, elsewhere they show considerable vertical range. In some localities, notably in the Southeast Area, it is impossible to identify the genus, hence the designation, "Graptolite zone".

the layers immediately underlying these but also being found in the Depauperate zone. To the south they rise higher in the section but in all cases they are index fossils of the Elgin beds in the northwest and the equivalent strata in the southeast.

VOGDESIA ZONE

As regards fossil content these beds likewise are best developed in the area around the towns of Elgin and Clermont. In this region, judging from the abundance of the remains of *Vogdesia vigilans*, this trilobite must have been present in numbers comparable to *Isotelus iowensis* which preceded it. Fragments of *Vogdesia* litter the surface of weathered slabs. They are mostly small angular fragments, tiny bits from all parts of the exoskeleton of the trilobite. The surface of these slabs is harsh and uneven. (See Plate IX.) They can not be split with ease. They usually appear to be less limy than the *Isotelus* beds.

The commonest of the fossils associated with *Vogdesia* are the large cephalopods. These are usually of the simple straight type but coiled forms occur.

Evidently the dead shells of the large cephalopods served as retreats or molting places for *Vogdesia* because rolled specimens of the trilobite can frequently be obtained by breaking the body chambers of the cephalopods. Indeed the surest way to obtain perfect specimens is to traverse one of the small stony creek beds and crack open all the water worn cephalopods encountered.

Since the typical *Vogdesia* beds are not widespread either horizontally or vertically Calvin's interpretation of them as an old beach deposit seems reasonable (13, p. 104). Certainly the broken condition of the fossils indicates wave action in shallow water—just as do the jumbled and telescoped shells of *Orthoceras sociale* at essentially the same horizon at Graf.

UPPER ELGIN FAUNA

Above the *Vogdesia* beds the Elgin frequently contains an abundant and varied fauna. It is chiefly a molluscoid fauna and greatly resembles the assemblage of fossils making up the "Cornulites zone" found at the top of the Maquoketa. In fact so similar are these two faunas that early workers in Howard and Winneshiek counties mistook this Elgin fauna for that of the upper Maquoketa, stating that the formation was very thin in this region. There is, however, at least one good index fossil for the upper zone, *Cornulites sterlingensis*. This species is found in large numbers in the upper Brainard and in equivalent strata to the southeast. It has never been found by the writer in the

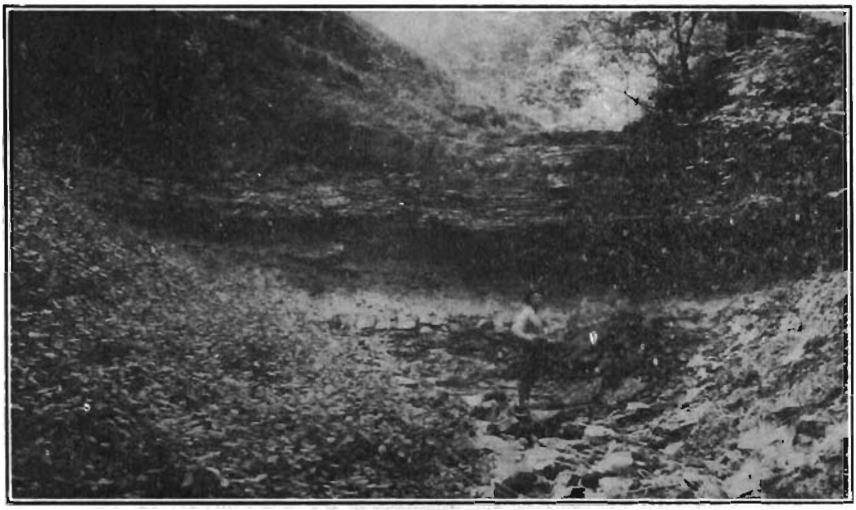

FIG. 75.—Patterson's spring, western half northwest quarter, section 20, Pleasant Valley township, Fayette county, Iowa. An excellent exposure of the Cornulites zone of the Northwest Area. Photo by Thomas.

Elgin or in the two members overlying it nor do any references to such an occurrence appear in the literature examined. In questionable cases the finding of this form will tell the horizon. In its absence other criteria will serve.

The fossiliferous slabs of the Upper Elgin, while they contain many fossils, are never crowded to the same extent as are those of the Cornulites zone. In the case of the latter the fossil fragments really make up the rock whereas in the Elgin the matrix in which the fossils are imbedded is prominent. The Elgin fossils are commonly silicified and often broken; this is not true of the upper fauna. Lastly, it should be remembered that beds of soft greenish clay and shale occur in the Cornulites zone but these are never found in the upper Elgin beds.

CLERMONT SHALE FAUNA

Little can be said of this fauna save that it is more diversified than heretofore supposed. Practically all of the species found also occur elsewhere at quite different horizons. About half of the species collected were molluscoids, most of these being wide ranging brachiopods. The shale is well developed in the Clermont area but has not been recognized elsewhere. This may be due in large part to the thinness of the member and to the fact that it is all shale. Careful searching may reveal additional outcrops but one suspects that it is more local than are the other members of the Maquoketa.

FORT ATKINSON LIMESTONE FAUNA

The fauna of the Fort Atkinson limestone is large and varied but its chief interest lies in its rare and unusual fossils. At the type locality, the quarry at the old blockhouse, near the town of Fort Atkinson, conditions for collecting were unusually good at the time of the writer's visits. The State of Iowa has purchased the ancient buildings and the surrounding ground to make a state park. Some of the buildings of the old fort are to be restored and in some cases rebuilt. For this purpose a large amount of stone has been taken out of the old quarry. Much of the quarrying was done some years ago as two long rows of weathered flags and blocks testify. The rock in these piles is soft, yellow or slightly bluish dolomite. On the surface of such slabs the white calcite of echinoderms stands out sharply, especially when the rocks are wet. The time to collect fossils at Fort Atkinson is on a rainy day and such was the writer's good fortune on two of his three visits there. The collections have been studied by A. O. Thomas and the writer and the results of these studies have appeared recently in a separate paper.[(118)]

Most of the species are represented by several specimens, frequently on the same slab. The old quarry face and the rubble at its foot yielded only a few fossils so that one is not surprised that earlier workers failed to find this very unusual echinoderm faunule.

Another remarkable fossil from the Fort Atkinson limestone is a cup coral, *Lindströmia solearis* n.s.

CORNULITES ZONE OF THE UPPERMOST MAQUOKETA

This fauna has been mentioned previously and compared with the fauna of the Upper Elgin. It is the best known and one of the most widely distributed of the Maquoketa faunas in Iowa. Fossiliferous slabs from this zone have been quarried at the classic locality of Patterson's spring in Fayette county and shipped to many institutions over the country. Its large fossils are more abundant and better preserved than those of any other Maquoketa fauna.

FIG. 76.—Weathered exposure of Maquoketa in south-central section 29, Fairfield township, Jackson county, Iowa. The highly fossiliferous Cornulites zone is exposed.

FAUNAL LISTS

In the table which follows the Maquoketa fossils studied to date are listed with their vertical ranges. This list will be considerably longer when the paleontological studies are completed. Doctor W. H. Shideler has identified the bryozoa and Doctor Aug. F. Foerste the cephalopods.

A careful study of all available literature shows that a total of about three hundred species has been reported from the Maquoketa. Actually this figure is too large, being padded by duplications due to erroneous identification.

Thus, in the past a number of workers have identified Maquoketa species with forms occurring in the Richmond of the Ohio valley. Later work proved many of these to be incorrect and yielded distinct Maquoketa species. A total of 38 species was reported first from the Cincinnati area and later from the Maquoketa. Most of these are molluscoids. The writer is now engaged in checking these systematically by comparing Maquoketa material with specimens from the Ohio valley. In almost every case persistent differences of at least varietal rank have been found. As a result of this work several new species and varieties are described in the present paper.

Fossils of the Maquoketa Shale

	Brainard	Fort Atkinson	Clermont	Elgin	Depauperate Zone	Cornulites SE. Area
Astylospongia sp. ?				x		
Hindia parva ? Ulrich				x	x	
Streptelasma haysii (Meek)		x				
Streptelasma sp.			x			x
Lindströmia solearis n.s.		x				
Tetradium ontario Hall			x		x	
Mastigograptus cf. M. gracillimus (Lesquereux)				x		
Climacograptus (Mesograptus) putillus (Hall)				x		
Climacograptus ulrichi Ruedemann				x*		
Diplograptus peosta Hall				x	x	
Glossograptus (Orthograptus) cf. quadrimucronatus (Hall)				x		
Lasiograptus sp.				x		
Serpulites sp.					x	
Cornulites sterlingensis (Meek and Worthen)	x					x
Lepidocoleus sp. ?					x	
Iowacystis sagittaria Thomas and Ladd		x				
Pleurocystites beckeri Foerste						x
Pleurocystites clermontensis Foerste		x				
Sygcaulocrinus typus Ulrich		x				
Ectenocrinus raymondi Slocom				x		
Dendrocrinus kayi Slocom	x					
Carabocrinus slocomi Foerste			x			
Carabocrinus slocomi costatus Foerste		x				x
Porocrinus fayettensis Slocom		x				
Lichenocrinus minutus Foerste	x		x	x		x
Stomatopora arachnoidea (Hall)						x
Corynotrypa curta Bassler						x
Corynotrypa delicatula (James)						x
Proboscina auloporoides (Nicholson)	x					x
Proboscina frondosa (Nicholson)	x					x
Diploclema varians Shideler n.s.	x					
Ceramoporella irregularis (Whitfield)						x
Crepipora peculiaris Shideler n.s.	x					
Anolotichia crassa Shideler n.s.				x		
Spatiopora iowensis Ulrich				x*	x	
Atactoporella sp.						x
Peronopora decipiens (Rominger)						x
Homotrypa nodulosa ? Bassler						x
Homotrypa wortheni ? (James)						x
Homotrypa sp.		x				x
Homotrypella rustica Ulrich	x		x?			x?
Prasopora elginensis Shideler n.s.				x		
Mesotrypa maquoketensis Shideler n.s.				x		

Fossils of the Maquoketa Shale (Continued)

	Brainard	Fort Atkinson	Clermont	Elgin	Depauperate Zone	Cornulites SE. Area
Mesotrypa patella delicatula Shideler n.var.	x					
Mesotrypa sp.	x					x
Heterotrypa sp.						x
Stigmatella incerta Shideler n.s.	x					
Constellaria polystomella Nicholson						x
Constellaria punctata (Whitfield)				x		x
Constellaria robusta Shideler n.s.		x				
Bythopora delicatula (Nicholson)	x					x
Bythopora meeki (James)	x					x
Bythopora striata Ulrich	x					x
Eridotrypa brainardensis Shideler n.s.	x					
Eridotrypa simulatrix ? (Ulrich)						x
Lioclemella annulifera (Whitfield)	x					x
Lioclemella fusiformis (Whitfield)						x
Lioclemella solidissima (Whitfield)						x
Rhombotrypa quadrata (Rominger)	x	x		x		x
Rhombotrypa subquadrata (Ulrich)	x					x
Hallopora fayettensis Shideler n.s.	x					
Hallopora persimilis Shideler n.s.	x					
Hallopora subnodosa ? (Ulrich)						x
Hallopora sp.						x
Calloporella ? lens (Whitfield)						x
Batostoma rugosum (Whitfield)	x?					x
Batostoma sp.						x
Hemiphragma nodosa (Ulrich)						x
Diplotrypa obscura Shideler n.s.					x	
Anaphragma mirabile Ulrich						x
Trematopora granulata Whitfield						x
Chasmatopora sp.						x
Fenestella granulosa Whitfield	x					
Helopora elegans Ulrich	x					
Helopora thomasi Shideler n.s.						x
Sceptropora facula Ulrich	x					
Ptilodictya sp.						x
Arthropora shafferi (Meek)	x				x?	x
Rhinidictya sp.					x	
Dicranopora emacerata (Nicholson)	x					x
Dicranopora fragilis (Billings)	x					x
Pachydictya sp.						x
Leptobolus occidentalis Hall					x	x
Lingula beltrami Winchell and Schuchert		x				
Lingula changi Hussey				x	x	
Lingulasma schucherti Ulrich			x			x
Lingulops whitfieldi Hall				x*		
Acrothele ? richmondensis n.s.					x	
Conotreta obliqua n.s.					x	
Trematis sp.				x*		
Orbiculoidea sp.					x	
Schizotreta minutula Winchell and Schuchert				x		
Crania sp.			x	x		
Plectorthis (Austinella) whitfieldi (N. H. Winchell)	x	x	x	x		x

Fossils of the Maquoketa Shale (*Continued*)

	Brainard	Fort Atkinson	Clermont	Elgin	Depauperate Zone	Cornulites SE. Area
Platystrophia sp.	x					x
Platystrophia elginensis n.s.				x		
Hebertella (Glyptorthis) insculpta maquoketensis n. var.	x	x	x	x		x
Hebertella sinuata prestonensis n. var.	x					x
Dalmanella corpulenta (Sardeson)	x	x	x	x		x
Dalmanella macrior (Sardeson)	x	x	x	x		x
Dalmanella porrecta (Sardeson)				x		
Dalmanella sp.					x	
Dinorthis proavita (Winchell and Schuchert)			x	x		
Dinorthis (Plaesiomys) subquadrata occidentalis n. var.	x		x	x		x
Plectambonites precosis (Sardeson)				x		
Plectambonites recedens (Sardeson)				x		
Plectambonites saxeus (Sardeson)				x		
Leptaena raymondi Bradley				x		
Leptaena unicostata (Meek and Worthen)	x					x
Rafinesquina altidorsata Bradley		x	x			
Rafinesquina kingi (Whitfield)		x				x
Rafinesquina subquadrata Bradley						x
Strophomena abscissa Bradley		x	x	x		
Strophomena acuta (Winchell and Schuchert)				x		x
Strophomena fluctuosa occidentalis Foerste			x			
Strophomena planodorsata Winchell and Schuchert				x		
Strophomena sp.						x
Strophomena sp.		x				
Holtedahlina atkinsonensis n.s.	x	x				
Triplecia (California) ulrichi Winchell and Schuchert				x		
Parastrophia sp.				x		
Rhynchotrema anticostiense ? (Billings)	x					x
Rhynchotrema capax altirostratum n. var.				x		
Rhynchotrema neenah (Whitfield)	x			x		x
Zygospira sp.	x		x	x		x
Zygospira sp.					x	
Priscochiton elongatus n.s.					x	
Priscochiton sp.					x	
Saffordia sulcodorsata (Ulrich)				x		
Saffordia ventralis Ulrich				x		
Ctenodonta calvini Ulrich				x*		
Ctenodonta fecunda (Hall)					x	
Ctenodonta obliqua (Hall)					x	
Ctenodonta recurva (Ulrich)				x		
Ctenodonta simulatrix Ulrich				x		
Ctenodonta fillmorensis n.s.				x		
Clidophorus neglectus Hall					x	
Cyrtodonta grandis luculenta (Sardeson)				x		
Vanuxemia bristolensis n.s.				x		
Whitella minnesotensis n.s.				x		
Whitella sterlingensis (Meek and Worthen)				x		
Pterinea iowensis n.s.						x

Fossils of the Maquoketa Shale (Continued)

	Brainard	Fort Atkinson	Clermont	Elgin	Depauperate Zone	Cornulites SE. Area
Byssonychia sp.						x
Byssonychia tenuistriata Ulrich			x			x
Conocardium sp.					x	
Modiolopsis excellens Ulrich				x		
Archinacella rotunda Ulrich and Scofield				x*		
Cyrtolites conradi Hall					x	
Cyrtolites disjunctus Ulrich and Scofield				x		
Sinuites concinna (Ulrich and Scofield)				x		
Salpingostoma imbricatum Ulrich and Scofield				x		
Bellerophon lirata Hall					x	
Microceras patersoni (Hall)					x	
Pleurotomaria (Lophospira ?) depauperata (Hall)					x	
Lophospira quadrisulcata Ulrich and Scofield				x		
Lophospira sp.					x	
Hormotoma gracilis multivolvis Ulrich and Scofield				x		
Hormotoma sp.					x	
Liospira micula (Hall)					x	
Plethospira semele (Hall)				x*		
Clathrospira sp.	x					x
Trochonema (Eunema) minnesotensis n.s.				x		
Cyclonema jacksonense n.s.	x					x
Cyclonema sp.				x		
Cyclora sp.					x	
Meekospira subconica Ulrich and Scofield				x		
Hyolithes parviusculus (Hall)					x	
Coleolus iowensis James					x	
Conularia pumila n.s.					x	
Conularia putilla n.s.					x	
Conularia sp.		x				
Endoceras kayi Foerste n.s.				x		
Cyclendoceras clermontense Foerste n.s.				x		
Cyclendoceras atkinsonense Foerste n.s.				x		
Orthoceras sociale Hall				x*		
Geisonoceras ? clermontense Foerste n.s.				x		
Ephippiorthoceras laddi Foerste n.s.				x	x	
Kionoceras thomasi Foerste n.s.				x	x	
Kionoceras postvillense Foerste n.s.				x		
Kionoceras tenuitectum Foerste n.s.					x	
Spyroceras cf. perroti (Clarke)				x		
Spyroceras calvini Foerste n.s.				x*		
Spyroceras clermontense Foerste n.s.		x	x	x		x
Sactoceras maquoketense Foerste n.s.				x		
Charactoceras baeri (Meek and Worthen)				x		
Charactoceras laddi Foerste n.s.				x		
Charactoceras ? clermontense Foerste n.s.				x		
Armenoceras clermontense Foerste n.s.				x		
Beloitoceras whitneyi (Hall)				x*	x	
Beloitoceras ? discrepans Foerste n.s.						x
Vogdesia vigilans (Meek and Worthen)				x		
Isotelus iowensis (Owen)		x		x		

Fossils of the Maquoketa Shale (Continued)

		Brainard	Fort Atkinson	Clermont	Elgin	Depauperate Zone	Cornulites SE. Area
Isotelus rejuvenis Raymond					x		
Amphilichas bicornis (Ulrich)					x		
Encrinurus cristatus Clarke					x		
Cybeloides iowensis Slocom					x		
Calymene fayettensis Slocom				x	x		
Calymene gracilis Slocom		x					x
Calymene mammillata Hall						x	
Ceraurus elginensis Slocom					x		
Sphaerocoryphe maquoketensis Slocom					x		
Pterygometopus fredricki Slocom					x		
Aparchites fimbriatus (Ulrich)					x		
Primitia cf. cincinnatiensis (Miller)						x	
Primitia gibbera Ulrich					x		
Primitia tumidula Ulrich					x		
Ulrichia bivertex ? (Ulrich)						x	
Tetradella quadrilirata (Hall and Whitfield)		x					
Tetradella simplex (Ulrich)		x					
Beyrichia parallela (Ulrich)		x					
Bythocypris ? sp.						x	
Drepanodus acinaciformis n.s.						x	
TOTALS	212	46	23	21	93	44	71

* Southeast Area at an equivalent horizon.

DESCRIPTIONS OF FOSSILS

Phylum **COELENTERATA**

Class **ANTHOZOA**

Subclass **Tetracoralla** Haeckel

Family **Zaphrentidae** Milne-Edwards and Haime

Streptelasma haysii (Meek)

Plate IV, figs. 1-5.

1865. *Zaphrentis haysii* Meek, Amer. Jour. Sci. and Arts, 2d ser., 40, p. 32.
1925. *Streptelasma haysii* Kirk, Amer. Jour. Sci., 10, pp. 445 to 446.

Original description:

"Corallum obconical, distinctly curved, rapidly expanding from a pointed base; length, about two inches; breadth, near the summit, 1.40 inches; sometimes showing on the convex side, two broad, distinct, shallow, longitudinal furrows, extending the whole length, so as to give that side a trilobate appearance. Epitheca thick, and, where not worn, concealing the septa within; surface showing small wrinkles of growth, which are most distinct near the summit. Calice, apparently rather deep, (filled with stony matter in all the specimens examined); principal radial septa about sixty, rather stout and rigid, as seen around the margins of the calice, where about ten of them may be counted in a space of half an inch; alternating with these there is a shorter and weaker series.

The trilobate appearance of the outer or convex side in the type of this species together with its small wrinkles of growth, give it much the aspect of some of the merely arched species of *Platyceras,* for which it might be mistaken, when the calice is filled with stony matter. As some of the specimens, however, apparently not differing in other respects, do not present this trilobate appearance. it may not be constant."

Meek's specimens are now a part of the collections of the U. S. National Museum. There are one nearly complete individual and five fragments. Several of the latter may not belong to *S. haysii* and the single complete individual, here figured for the first time, is designated the holotype. On this specimen the trilobate appearance is due, not so much to broad shallow furrows, as to the intervening angles. The most prominent of these is on the outside curve, the other two being at the sides.

The Maquoketa specimen figured on Plate IV seems identical with Meek's type from the far north. The surface markings are more distinct and the wrinkles of growth more numerous. The angulation is slightly sharper in the older portion of the corallum. Like the type it has been somewhat riddled by a small boring sponge or similar organism.

According to Kirk *S. haysii* is

"very close to or identical with a *Streptelasma* in the lower part of the Bighorn dolomite of Wyoming and is nearly related to *Streptelasma* in contemporaneous deposits of Manitoba. The form represents the inception of an evolutionary line that culminated in the curious *Streptelasma trilobatum* of Whiteaves, which was originally described by Lambe as *Streptelasma latusculum* var. *trilobatum*. *Streptelasma haysii* (Meek) is of the type of *Streptelasma angulatum* (Billings) from Anticosti, but close comparisons are impossible as Billings' species is stated to be based on immature individuals." (62, p. 446.)

Horizon and localities.—Holotype from Cape Frazier between latitude 80 degrees and 81 degrees north, longitude 70 degrees west. Holotype No. 25683 U. S. Nat. Museum.

Maquoketa specimen from the upper beds of the Elgin member (possibly Clermont shale member), east of the bridge over Rogers' creek at south end of "10th Ave.", Fort Atkinson, Iowa. No. 2-050 State University of Iowa.

Lindströmia solearis n.s.

Plate IV, Figs. 6-12.

Corallum elliptical as seen from above; tapering gradually for about three-fourths of its total length, thence more rapidly to the apex below. Apex distinctly flattened parallel to the plane of the alar septa; pinched slipper-like to a broad point almost at right angles to the longitudinal axis of the corallum. The flattened tip bears a broad median depression on the outside curve and one much less pronounced on the inside curve.

Calyx very deep, slightly over half the total length of the cup. Walls comparatively thin. Septa numbering about 100, alternate ones reaching the base of the cup; these are thin and platy, showing an irregular lobate profile as viewed from the side. Between each two at the margin of the cup is a small septum which continues but a very short distance toward the bottom of the calyx. Fossula prominent, located on the inside curve. Bottom of the calyx composed chiefly of partly fused septa and raised to form a broad central cone from the center of which a flattened columella, or peg, projects upward for a distance of two millemeters. The columella is flattened parallel to the plane of the cardinal septum and is one millemeter broad at the exposed base but pinches gradually to a sharp edge, broadly rounded as viewed from the side. It is continuous with the cardinal septum on only one side.

Theca marked by a few broad encircling wrinkles and numerous fine longitudinal striae; these lines are parallel on the broad face of the outside curve, on the opposite face they converge toward a single median line which marks the position of the cardinal septum. They also converge to a similar line on each side, the alar septum.

Measurements of the holotype: length 17 mm., width of calyx, plane of alar septum 22 mm., plane of cardinal septum 19 mm., depth of calyx 9 mm.

One perfect and three practically complete specimens have been collected in addition to fragments. The best of these were found by A. O. Thomas and H. J. Tysor. All are from the same locality and agree in all important features. One specimen is evidently a young form; it shows a calyx which is subtriangular in outline, as would be expected.

Savage, in his Fayette county report, mentions "an undescribed species of *Streptelasma* in which the septa unite at the center in such a manner as to form a columella-like elevation on the floor of the calyx" (96, p. 473). He reports this from the top of the Elgin (No. 5 of the General Section), having collected it from a weathered shale outcrop in the wagon road along the south bank of Little Turkey river one mile west of Eldorado (near middle of east side of section 13, Auburn township). This might be the species here described.

The Maquoketa form is very close to an undescribed species collected by Edwin Kirk in the massive beds at the base of the

Big Horn dolomite in Wyoming and at other localities farther south.

Horizon and locality.—All specimens from the Fort Atkinson limestone member, three-fourth mile southwest of Ossian in the northwest quarter of section 15, Military township, Winneshiek county, Iowa. Holotype No. 2-051, State University of Iowa. Paratype *A* deposited as No. 71926 in the United States National Museum. Paratype *B*, an immature specimen, No. 2-052, State University of Iowa.

Phylum **MOLLUSCOIDEA**

Class **BRACHIOPODA** Duméril

Order **PROTREMATA** Beecher

Family **Orthidae** Woodward

Hebertella (*Glyptorthis*) *insculpta maquoketensis* n. var.

Plate IV, figs. 13-16; Plate V, figs. 1, 2.

Shell small, subquadrate in outline, wider than long. Width along hinge usually slightly less than greatest width of shell. Cardinal angle usually obtuse but in some specimens a right angle or even slightly acute. Lateral margins straightened or very gently convex, anterior margin straightened or bearing a shallow median reëntrant. Convexity of valves nearly equal. Pedicle valve deepest posterior to the midpoint, thence sloping uniformly to the sides. Anteriorly the surface is in many cases elevated to form a low but distinct median ridge capped by a single striation. Beak erect, prominent, extending posteriorly beyond that of opposing valve; cardinal area high and slightly curved. Interior exhibiting large, well developed hinge teeth supported by strong dental plates. Instead of the usual obcordate muscular impression there is developed a most unusual subrectangular platform for the attachment of the adductor muscles. This platform rises near the beak and extends forward nearly half way to the anterior margin of the shell. In this distance its width doubles, being one millimeter in width posteriorly and two millimeters anteriorly. Anteriorly the platform ends abruptly; somewhat excavated at the sides and below the anterior end save at the midpoint where it is supported by a median septum. The surface of the platform is slightly concave and bears several indistinct longitudinal striations. The diductor muscular impressions appear as longitudinal concave depressions on either side of the platform, each being slightly narrower than the platform separating them. Adductor muscle scars appear as elongated triangular areas on either side of the diductor scars but are not depressed as much as the latter. Ovarian areas large, as in typical specimens of *H. insculpta,* and marked by similar elevated, bifurcating lines that radiate anteriorly and laterally. Margin of valve crenulate.

Brachial valve with greatest convexity somewhat posterior to the midpoint, bearing a prominent median sinus which is bordered by elevated ridges which separate it from the slightly reflected cardinal extremities. Beak inconspicuous, incurved, cardinal area low. Interior unknown.

Surface of both valves marked by numerous radiating striae which increase, usually, by bifurcation. These are crossed by many fine imbricating lines of growth and, anteriorly in adult specimens, by a few more prominent lines of growth.

Measurements of the types are as follows:

	Length	Width	Convexity
Cotype A	14.7 mm.	17.6 mm.	9.2 mm.
Cotype B (Pedicle valve)	15.2 mm.	17.4 mm.	5.0 mm.
Paratype	15.0 mm.	18.8 mm.	9.4 mm.

When compared with *H. insculpta* from the Ohio valley the Maquoketa variety is seen to be smaller, proportionately narrower and more convex. The sinus on the brachial valve is deeper and the bordering ridges are more pronounced while the cardinal angles are more often acute and the pedicle ridge occurs more frequently. The interior of the pedicle valve differs markedly from the typical *H. insculpta.* The low double ridge that forms the adductor muscle scar in the Ohio valley specimens has been elevated to form a distinct platform in the Maquoketa variety. It must be admitted that the writer has at hand only one interior of the new variety here described and its features may not prove to be constant. However, dozens of interiors of Ohio valley specimens have been examined and though they exhibit minor variations no specimen approaches the Maquoketa form.

The species is very similar to *H. bellarugosa* (Conrad) and is probably a direct descendent of this species, which is found in the older Ordovician rocks of the same area. *H. bellarugosa* is smaller, has a less convex brachial valve, more prominent lines of growth, and lacks the interior characters of the Maquoketa form.

Horizon and localities.—An abundant Maquoketa species over the entire Iowa area. Found in all members but not in the Depauperate zone. Most abundant in the Upper Elgin beds. All types from Upper Elgin beds as exposed along a road between the north ends of sections 23 and 24, Springfield township, Winneshiek county, Iowa. Cotype *A* No. 6-6500, State University of Iowa; cotype *B* No. 6-6502, State University of Iowa; paratype No. 71986, U. S. Nat. Museum.

Hebertella sinuata prestonensis n. var.

Plate V, figs. 3-6.

Shells large, gibbous, subquadrate in outline, wider than long. Pedicle valve much less convex than brachial; deepest in umbonal area, which lies close to posterior margin of valve. A broad and deep median sinus is present giving a sinuous anterior margin. Beak sharp, terminating a high cardinal area which is but slightly curved.

Brachial valve highly convex, deepest at about midpoint. A low broad median elevation arises in the anterior third of the valve and meets the sinus of the opposite valve anteriorly but is proportionately much less conspicuous. Cardinal extremities strongly reflexed, beak inconspicuous, cardinal area low and strongly curved.

Surface of both valves marked by coarse striae which increase by bifurcation. Concentric lines of growth are prominent on the anterior portions of mature shells. In general the specimens from the Southeast Area are larger and are more coarsely striated than these from the Northwest Area (Brainard member).

Measurements of the cotypes as follows:

	Length	Width	Convexity
Cotype A	36.2 mm.	41.8 mm.	25.0 mm.
Cotype B	38.8 mm.	42.3 mm.	22.0 mm.

The Maquoketa form here described is more closely related to *H. sinuata* Hall than to any other species of the genus. In the Maquoketa specimens the central portion of the pedicle valve is almost invariably much flattened, the cardinal angles of the brachial valve are reflected, and the striae are very coarse. The brachial fold is never prominent nor are the cardinal angles rounded. It is true that unusual specimens of *H. sinuata* may be exceedingly close to the Maquoketa variety but careful study seems to reveal distinctions in all cases. If large lots were to be mixed together, nine-tenths of them could be separated without the slightest difficulty.

When compared with specimens of *H. occidentalis* from the type locality of the Richmond differences may be noted: In the Ohio valley specimens (1) the median depression on the pedicle valve is well developed in the umbonal region, (2) the beak of the brachial valve is more strongly incurved, (3) the beak of the pedicle valve is more curved near the tip, (4) the cardinal angles are more acute, (5) the reëntrant in the anterior margin is deeper, and (6) they are smaller and less coarsely striated.

In general size, shape and proportion the Maquoketa form is similar to *H. subjugata* (Hall). In the latter species, however, the beak of the brachial valve is more strongly incurved and the cardinal area of the pedicle valve is narrower and more curved.

Horizon and localities.—Characteristic of the Cornulites zone of the entire Iowa belt; it occasionally is found in the shales a short distance below this zone but no specimens have been found in other members. Cotypes from the north-central part of section 16, Washington township, Jackson county, Iowa, near the town of Preston. Cotype *A* is No. 6-6503, State University of Iowa. Cotype *B* No. 71927, U. S. National Museum.

Family **Rhipidomellidae** Schuchert

Dinorthis (*Plaesiomys*) *subquadrata occidentalis* n. var.

Plate V, figs. 7-9.

This form is so closely related to the well known *Dinorthis subquadrata* that a detailed description is scarcely necessary.

Medium to large, plano-convex, subquadrate in outline, wider than long. Pedicle valve much flattened except in the umbonal area, where it is slightly elevated; in some shells this elevation is continued anteriorly as an indistinct median ridge. Beak minute, cardinal area low, though higher than that of opposing valve. Length of the cardinal area but little more than half the width of the valve owing to the rounding of the cardinal angles.

Brachial valve notably convex, deepest at about the midpoint; beak small and incurved over low cardinal area. A median depression, scarcely discernible on some specimens, extends from the beak to the anterior margin. Cardinal extremities very slightly reflected.

Both valves marked by numerous radiating plications (about 60 on each valve) which increase by bifurcation on the pedicle valve and by implantation on the brachial. Several of the plications on each valve terminate against the cardinal area without reaching the lateral margins.

Measurements of the holotype: length, 18.2 mm.; width, 22.5 mm.; greatest convexity, 8.8 mm.

In the Maquoketa variety of *D. subquadrata* the cardinal angles are distinctly rounded. This lessens the straightness of the sides and makes the entire shell appear elliptical rather than quadrate in outline. Correlated with this is a shortening of the hinge line.

Horizon and localities.—Found throughout the Maquoketa except in the Depauperate zone and in the Fort Atkinson member. Never in abundance. Holotype No. 6-6504, State University of Iowa, from the Elgin member, north of Postville, Iowa, along Primary Road No. 51.

Order TELOTREMATA Beecher

Family **Rhynchonellidae** Gray

Rhynchotrema capax altirostratum n. var.

Plate V, figs. 10-16.

Shell medium to large, subspheroidal. Pedicle valve shallower than the brachial with a prominent median sinus which extends from the umbo well into the opposite valve. Sinus steep-sided, the bottom being occupied by three (rarely two) broad simple plications. Beak sharp, curving over that of the opposite valve but not in contact with it, pierced by a circular pedicle opening. Cardinal slopes broad, concave near beak, flattened laterally and anteriorly. Posterior-lateral margin extends in a broad curve deeply into the brachial valve. Nine fairly coarse plications occur on either side of the sinus, being coarsest near the sinus.

Brachial valve deeper than the pedicle and bearing a low fold marked by three broad simple plications. This fold is prominent anteriorly but becomes obsolete before reaching the beak. Nine plications are usually visible on either side of the fold, the last four being somewhat indistinct. Beak broadly rounded and buried beneath that of the opposing valve. Cardinal slopes broad and flattened.

Surface of both valves covered by fine close set zig-zag lines of growth.

Silicified interiors of both valves and good internal molds are not uncommon in the Iowa material from the Upper Elgin beds. The interiors of the pedicle valve show the two prominent lateral hinge-teeth, between which lie the convex deltidial plates that partly close the pedicle opening. The interiors of the brachial valve reveal the median septum bearing the cardinal process, on either side of which are the stout crural processes. The dorsal sockets (for the reception of the teeth of the opposite valve) are also well shown; these lie on either side of the crural processes.

Measurements of the holotype: length, 21.2 mm.; width, 21.0 mm.; convexity, 21.1 mm.

The Maquoketa specimens described are closer to *R. capax* (Conrad) than to any other species of Rhynchotrema but exhibit the following differences when compared with specimens of *R. capax* from the type locality: 1) the beak of the pedicle valve of the Maquoketa variety is sharper and less curved, 2) the cardinal slopes are broader, more concave near the beak and more flattened away from it, 3) the posterior-lateral margins of the pedicle valve cut deeply into the brachial valve, 4) the plications are finer and more numerous.

R. perlamellosum (Whitfield) differs from the Maquoketa species here described in having stronger plications, more distant, though more prominent lines of growth, more distinctly plicated cardinal slopes, and in having the valves more nearly equal in depth.

Horizon and localities.—Elgin member of the Maquoketa. The holotype is from the upper Elgin beds of Winneshiek county. No. 6-6505, State University of Iowa. Paratype *A,* a mold of the interior from the same horizon, is No. 6-6506, State University of Iowa. Paratypes *B* and *C* (Nos. 6-6507 and 6-6508, State University of Iowa) are interiors from the same horizon in Orleans township, Winneshiek county.

Phylum **MOLLUSCA**

Class **PELECYPODA** Goldfuss

Order PRIONODESMACEA Dall

Family **Cyrtodontidae** Ulrich

Whitella minnesotensis n.s.

Plate V, fig. 17.

1890. *Whitella obliquata* (part) Ulrich, Amer. Geol., 6, pp. 177, 178, fig. 13e (not 13a-d).
1892. *Whitella obliquata* (part) Miller, N. A. Geol. Pal., 1st App. p. 702, fig. 1261e (not a-d).
1894. *Whitella obliquata* (part) Ulrich, Geol. Minnesota, 3, pt. 2, p. 565, pl. 40, fig. 32 (not 31).
1908. *Whitella obliquata* (part) Cumings, 32d Ann. Rep., Dep. Geol. Nat. Res. Indiana, p. 1024, pl. 48, fig. 10 c (not 10, 10a, 10b, 10d).
1909. *Whitella obliquata* (part) Grabau and Shimer, N. A. Index Fossils, 1, p. 415 (not fig. 537c).

The specimen here described as *Whitella minnesotensis* was named by Ulrich as one of the cotypes of *W. obliquata* in the first reference cited above. The other cotypes of this species are from the Richmond of the Ohio valley. These will remain the cotypes of *W. obliquata* Ulrich. The Minnesota specimen seems distinct and Doctor Ulrich agrees that it should be made the type of a new species. Ulrich's description of *W. obliquata* (as given in Geol. Minnesota, 3, pt. 2), in so far as it applies to this specimen, is quoted below:

"Shell large, oblique, subrhomboidal in outline, ... ventricose, with point of greatest convexity above the middle; beaks rather small, prominent, slightly incurved, situated nearly one-third of the length of the hinge line from its anterior extremity, umbonal ridge well marked, the cardinal slope concave. Anterior end small, narrowly rounded above, merging gradually into the evenly and only moderately convex ventral margin. . . . . Anterior muscle scar elongate. Hinge thin, simple posterior to the beaks, in front of them, with one long and slender horizontal tooth and several slightly oblique teeth above it."

The Minnesota specimen is not as strongly produced in the postero-basal region as are the Ohio specimens of *W. obliquata*. Rather the posterior end is broadly rounded, gently and uniformly, in almost a perfect semicircle from the median point on the ventral margin to near the posterior end of the hinge. This rounding of the posterior basal region serves to distinguish it from *W. obliquata* Ulrich, as here restricted.

Markings of the shell unknown as the single specimen at hand is a left valve whose exterior is firmly embedded in the matrix.

Measurements of the type: greatest length 39 mm.; greatest height 41 mm.; greatest convexity 12 mm. (one valve).

Horizon and locality.—Elgin member, Spring Valley, Minnesota. Holotype No. 46352, U. S. National Museum. Collected by E. O. Ulrich.

GEOLOGICAL HISTORY

Prior to the formation of the Maquoketa shale, other Richmond deposits had been laid down over much of the area now known as the Mississippi valley. Thus, in parts of Missouri and Illinois the Fernvale limestone, which unquestionably is Richmond in age, underlies the basal layers of the Maquoketa. To the north in Iowa and the adjoining state of Wisconsin, the Dubuque dolomite is the underlying formation. The exact age of the Dubuque is still in doubt. For a long time many workers have considered it a part of the Galena formation but as previously explained (p. 345), it is probably a portion of the Richmond, though its relations to the southern pre-Maquoketa rocks have not been carefully worked out.

It has not been proved that this pre-Maquoketa Richmond sea entirely withdrew before the arrival of the water carrying the oldest Maquoketa fauna, but in view of the sharp lithologic and faunal break, etc., it seems quite possible that this did occur. If it did, the land was low or the interval short, at least in the upper

Mississippi valley, for the physical evidence of an interval of emergence and erosion at the base of the Maquoketa is very obscure in this area. However, thickness and distribution of older Richmond beds practically establish unconformity by overlap.

The first life forms in the Maquoketa sea were the thousands of small organisms whose fossil remains now form the rock of the Depauperate zone. This assemblage is the most widespread of all Maquoketa faunas and marks the base of the formation over the entire upper Mississippi basin. To the south, it continues into Arkansas at the base of the Cason shale, and future work may greatly extend its range in this direction. In the northwest portion of the Maquoketa basin, this zone thins progressively and probably pinches out near the Iowa-Minnesota line. To the northeast, it is believed to have extended at least as far as the upper peninsula of Michigan. These facts of distribution support the author's belief that, like certain pre-Maquoketa faunas, this one entered from the south. This basal fauna is comprised mainly of species whose ancestors occur in older Cincinnatian and Trenton faunas. However, it contains a number of species which occur also in the immediately overlying graptolite shales, whose fossils, as Ulrich has pointed out (131, pp. 300, 301), have near relatives in the Utica, which is unquestionably a north Atlantic fauna. This Utica fauna extended far to the south, and it is believed that later (in the Richmond) its descendants migrated northward into the Mississippi valley. The shales overlying the Depauperate zone correspond to the Sylvan shale of Oklahoma, which Ulrich now believes came in from the south also.*

It is interesting to speculate regarding the conditions under which the small animals of the Depauperate fauna lived. At first the writer, knowing the fauna only as it is developed in the pyrite-filled shales of Jackson and Dubuque counties, Iowa, was inclined to view it as a true dwarf fauna living in the unhealthy ferruginous waters of a land-locked sea filled with decaying vegetation, such as that postulated by Loomis† in explaining the dwarf fauna of the Tully pyrite. Thus Loomis believed that the waters were surcharged with iron in solution, probably as a fer-

* Ulrich, E. O., verbal communication. March 18, 1928.

† Loomis, F. B., The Dwarf Fauna of the Pyrite Layer at the Horizon of the Tully Limestone in Western New York: Bull. 69, New York State Mus., pp. 892-920; 1903.

rous carbonate. This would be unfavorable to animal growth, as would also the sulphurretted hydrogen given off by decaying organic matter. The iron would be deposited as pyrite by the gases of decomposition ($FeCO_3 + 2H_2S + O \rightarrow FeS_2 + CO_2 + 2H_2O$). The carbonaceous character of the shales of the Depauperate zone and the occurrence of pyrite seem to support a belief in some such origin, but it seems more likely that the Maquoketa pyrite is a secondary deposit. This belief is supported by the observed facts of its distribution. The pyrite, with its associated sphalerite and other minerals, seems to be best developed in the area where the underlying Galena is highly mineralized. Such a distribution suggests that the minerals of the basal layers, like those of the Galena, are secondary ones. The widespread occurrence of pyrite throughout the Maquoketa, and the theory that this formation was the source of the Galena ores, seem to favor a belief in the secondary nature of the basal pyrite. It is true, however, that fossils are more abundant and better preserved in the dark mineralized shales than elsewhere. Of course, if the pyrite was deposited at a later date than the shale, it has no bearing on the question of depauperization.

Pure speculation leads one to consider the dwarfing effect of possible changes in the chemical composition of the sea water. Thus it is known that chemicals in solution affect the permeability of the cell wall. The outside layer of the animal cell is one molecule in thickness, and through this layer pass food, oxygen, etc. There is, therefore, a direct relation between the permeability of this wall and the size of the animal. In sea water a certain balance exists between the elements sodium, potassium, magnesium and calcium. Sodium has no effect upon the permeability of the cell wall, but potassium increases it, and, given an excess of this substance, large forms would result. Calcium and magnesium, on the other hand, decrease the permeability of the cell wall and an excess of these in sea water would undoubtedly cause dwarfing.*

If the Depauperate fauna is not a true dwarf fauna, it is still unusual, and at the present time no satisfactory explanation can be suggested for it.

Following widespread deposition of the beds carrying the De-

* Houser, G. L., verbal communication, 1925.

pauperate fauna, commenced a period of shale deposition which persisted in the Southeast Area until nearly two hundred feet of beds had accumulated. To the northwest, the deposits were more limy, and conditions were not so uniform. There were water connections between these two areas, however, for a time at least, as is shown by the occurrence of the same species of graptolite in the two areas. Locally, in the Southeast Area many of the Depauperate species lived on and a record of their existence in the Graf area is preserved 40 feet above the base of the formation. There is considerable evidence which indicates that these early Maquoketa waters were exceedingly shallow. In this connection may be mentioned the jumbled *Orthoceras* beds of Graf in which shells of *Orthoceras sociale* are often telescoped, one into the other, the internal septa being broken. This suggests wave action as do also the fragmentary remains of trilobites and other forms in the *Vogdesia* zone, which occupies a similar horizon in the Northwest Area.

While shale continued to be deposited in the Southeast Area, changes occurred in the northwest. The fauna of the lowest member, the Elgin, seems to indicate at least a temporary connection with northern waters. The occurrence of the northern coral *Streptelasma haysii* is in itself a striking bit of evidence. Much additional evidence, however, is forthcoming. The abundant and varied cephalopods of this Elgin member have been carefully studied by Foerste, and he finds their nearest relatives in that part of the Richmond which invaded North America from the Arctic regions.

"This is shown especially by the areal distribution of the genera *Charactoceras, Ephippiorthoceras, Armenoceras* and *Cyclendoceras.* Of these genera the first three, namely *Charactoceras, Ephippiorthoceras* and *Armenoceras,* ranged in Richmond times as far north as Cape Calhoun, on the extreme northwestern coast of Greenland, and as far northeast as the Island of Anticosti in the Gulf of St. Lawrence. Two of these genera, namely *Ephippiorthoceras* and *Armenoceras,* are found in the Richmond west of Hudson Bay. *Armenoceras* occurs also in southern Manitoba. *Ephippiorthoceras* and *Charactoceras* occur westward in those Richmond strata of Wyoming and Colorado whose affinities are regarded as Arctic. Associated with these two genera in Wyoming is *Cyclendoceras,* which is known also from similar Richmond strata of Arctic origin in Idaho.''*

Two of these, *Charactoceras* and *Ephippiorthoceras,* however, occur in the Fernvale below the Maquoketa. *Charactoceras* is the only one of the four genera that occurs in the Richmond of Ohio and Indiana.

The distribution of certain genera of cystoids, likewise, suggests the northern derivation of the Elgin fauna.

It is held, therefore, that the fauna of the Elgin member migrated from the north and did not, *as far as we now know,* spread farther south than the middle of the Iowa belt.

Following the formation of the Elgin beds depositional conditions changed and locally 15 feet of blue-green shale was deposited. These beds of the Clermont member are very similar lithologically to the shales of the Southeast Area, but the former are locally highly fossiliferous while the latter are comparatively barren.

The cherty and dolomitic limestones of the Fort Atkinson member overlie the Clermont shale. Here, as in the case of the Elgin, the fauna contains many unusual elements that suggest northern affinities. This is particularly true of the echinoderms and the corals. Among the latter is a species of *Lindströmia* here described for the first time. It is very close to an undescribed species occurring in many localities to the north and west in Richmond rocks whose northern derivation has been generally accepted. As far as is known this Fort Atkinson fauna is limited to the Northwest Area.

During the closing stages of Maquoketa time blue-green shale and finally interbedded thin shales and limestones were laid down rather widely over the upper Mississippi valley area. Perhaps these deposits were once much more widespread than now, but it is conceivable that their present distribution outlines roughly the small, shallow basin or basins in which they were formed.

It seems fairly certain that during most, if not all, of Maquoketa time the Mississippi valley sea was separated from the Ohio valley basin by a land barrier. With few exceptions only widespread and long-lived species are common to the two areas.

At the close of Maquoketa time the seas withdrew and some

* Foerste, Aug. F., Ms., 1927.

erosion, at least, took place. During Alexandrian time seas advanced and deposited sediments over portions of the Maquoketa, locally reworking the loose materials to form a basal conglomerate. It is doubtful if these deposits covered any considerable part of the Maquoketa. Later in the Silurian, the Hopkinton dolomite was deposited.

Here again, it seems doubtful if the sea covered entirely what we now know as the Maquoketa area, for to the north, in Iowa, the apparent pre-Devonian erosion of the Maquoketa is much greater than to the south. In places only a few feet of the Brainard shale is to be seen. In other sections the Brainard is entirely absent, and with it the Fort Atkinson limestone and Clermont shale. The basal conglomerate of the Devonian can be seen resting directly on rocks bearing the fauna of the Upper Elgin. In such places the total thickness of the Maquoketa is less than one hundred feet. It is possible, of course, that the intervening rocks were never deposited in this northern area.

Local uplift with gentle arching of the strata seems to have occurred after the Silurian (at least after the Hopkinton age) and considerably before Pennsylvanian time. An example of this is seen in the Preston inlier. Here it seems that the Maquoketa and Hopkinton were bowed up and the latter completely removed in places, so that when the Pennsylvanian sea advanced its conglomerates, sands and shales were deposited upon the exposed but little eroded Maquoketa.

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PLATE IV.

Streptelasma haysii (Meek).

Figs. 1, 2. Views of a Maquoketa specimen from Winneshiek county, Iowa. Note the tendency toward trilobation. No. 2-050 State University of Iowa.

Figs. 3-5. Meek's type from Ellesmereland, figured for the first time. No. 25683 U. S. Nat. Museum.

Lindströmia solearis Ladd n. s.

Figs. 6-8. Views of the holotype. Fort Atkinson member, Winneshiek county, Iowa. No. 2-051 State University of Iowa.

Figs. 9-11. Similar views of paratype *A*. No. 71926 U. S. Nat. Museum.

Fig. 12. Calycinal view of paratype *B*, a young specimen. No. 2-052 State University of Iowa.

Hebertella (*Glyptorthis*) *insculpta maquoketensis* Ladd n. var.

Figs. 13-15. Brachial, pedicle, and posterior views of cotype *A*. Elgin member, Winneshiek county, Iowa. No. 6-6500 State University of Iowa.

Fig. 16. Pedicle view of paratype from the same horizon. No. 71986 U. S. Nat. Museum.

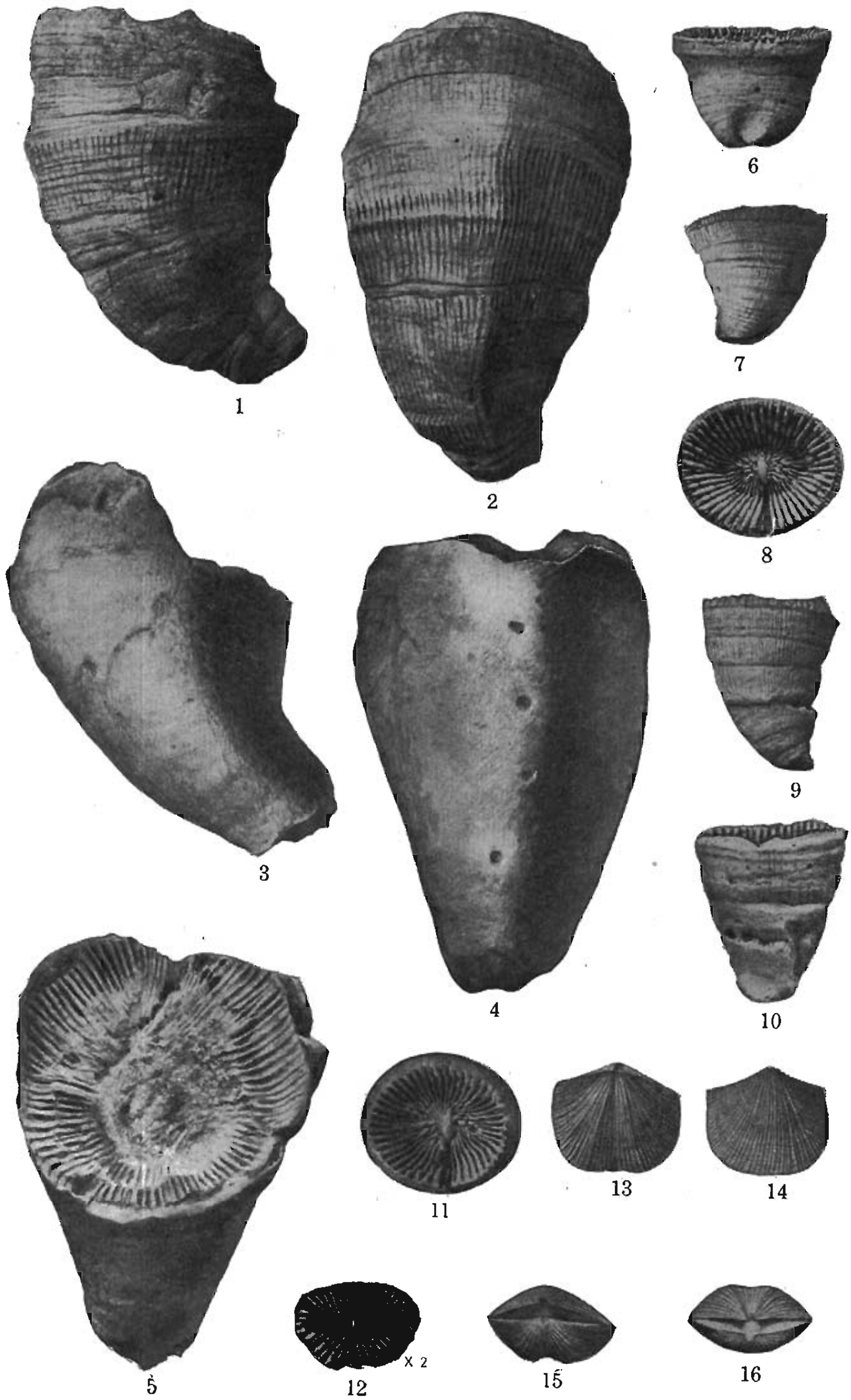
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PLATE V.

Hebertella (Glyptorthis) insculpta maquoketensis Ladd n. var.

Fig. 1. Pedicle view of cotype *A*. Elgin member, Winneshiek county, Iowa. No. 6-6500 State University of Iowa.

Fig. 2. Interior of pedicle valve, cotype *B*, from the same horizon and locality as the holotype. No. 6-6502 State University of Iowa.

Hebertella sinuata prestonensis Ladd n. var.

Fig. 3. Brachial view of cotype *B*, Cornulites zone, near Preston, Jackson county, Iowa. No. 71927 U. S. Nat. Museum.

Figs. 4-6. Pedicle, anterior, and posterior views of cotype *A*, near Preston, Jackson county, Iowa. No. 6-6503 State University of Iowa.

Dinorthis (Plaesiomys) subquadrata occidentalis Ladd n. var.

Figs. 7-9. Pedicle, brachial, and posterior views of holotype. Elgin member near Postville, Allamakee county, Iowa. Note rounded cardinal angles. No. 6-6504 State University of Iowa.

Rhynchotrema capax altirostratum Ladd n. var.

Figs. 10-12. Brachial, pedicle, and lateral views of the holotype. Upper Elgin beds, Winneshiek county, Iowa. No. 6-6505 State University of Iowa.

Figs. 13, 14. Pedicle and brachial views of a mold of the interior. Elgin member, Lincoln township, Winneshiek county, Iowa. Paratype *A*, No. 6-6506 State University of Iowa.

Figs. 15, 16. Interiors. Paratypes *B* and *C*. Elgin member, Orleans township, Winneshiek county, Iowa. Nos. 6-6507 and 6-6508 State University of Iowa.

Whitella minnesotensis Ladd n. s.

Fig. 17. Interior of left valve of holotype. Elgin member, Spring Valley, Minnesota (after Ulrich). No. 46352 U. S. Nat. Museum.

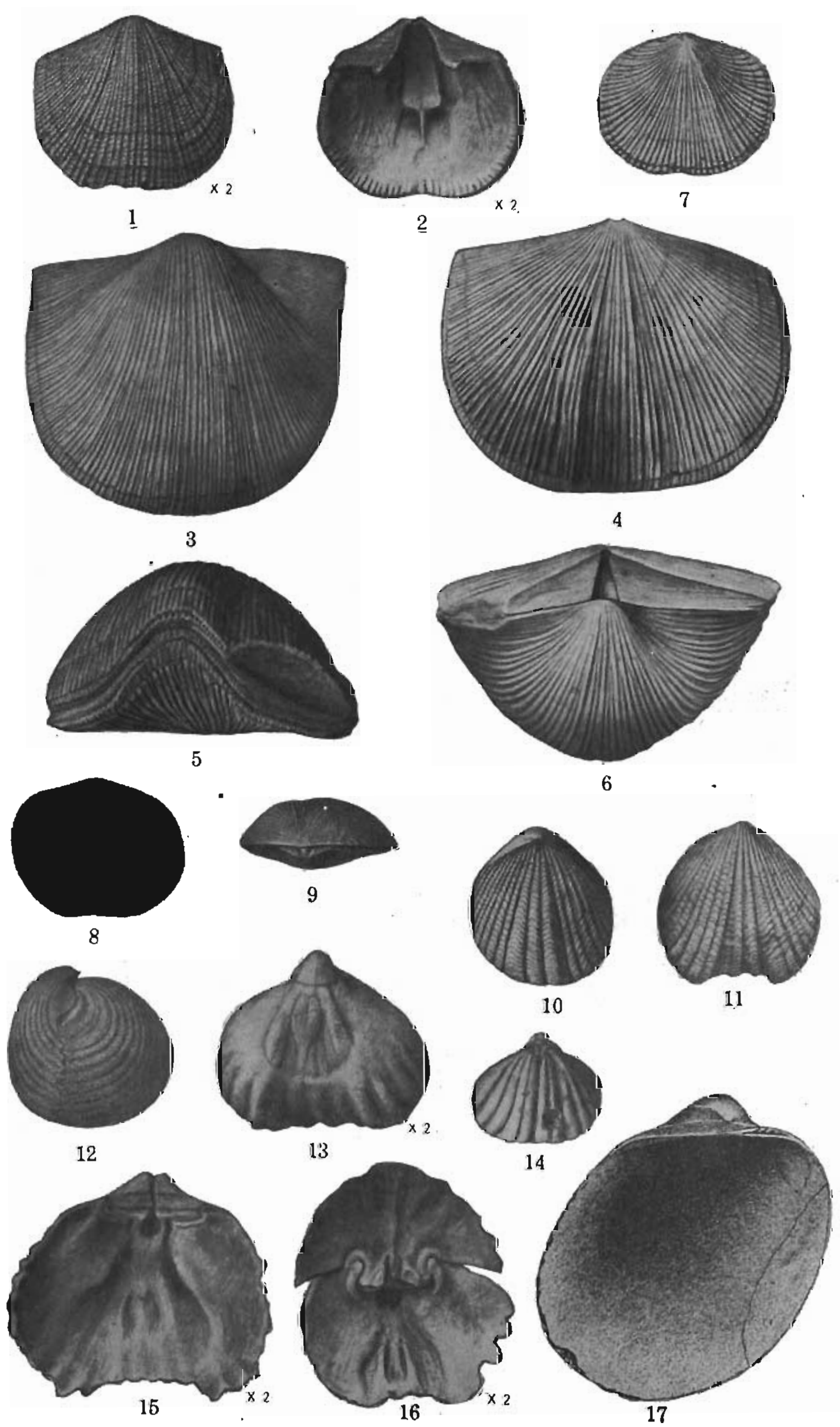
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PLATE VI.

Fossiliferous slab from the Depauperate zone.

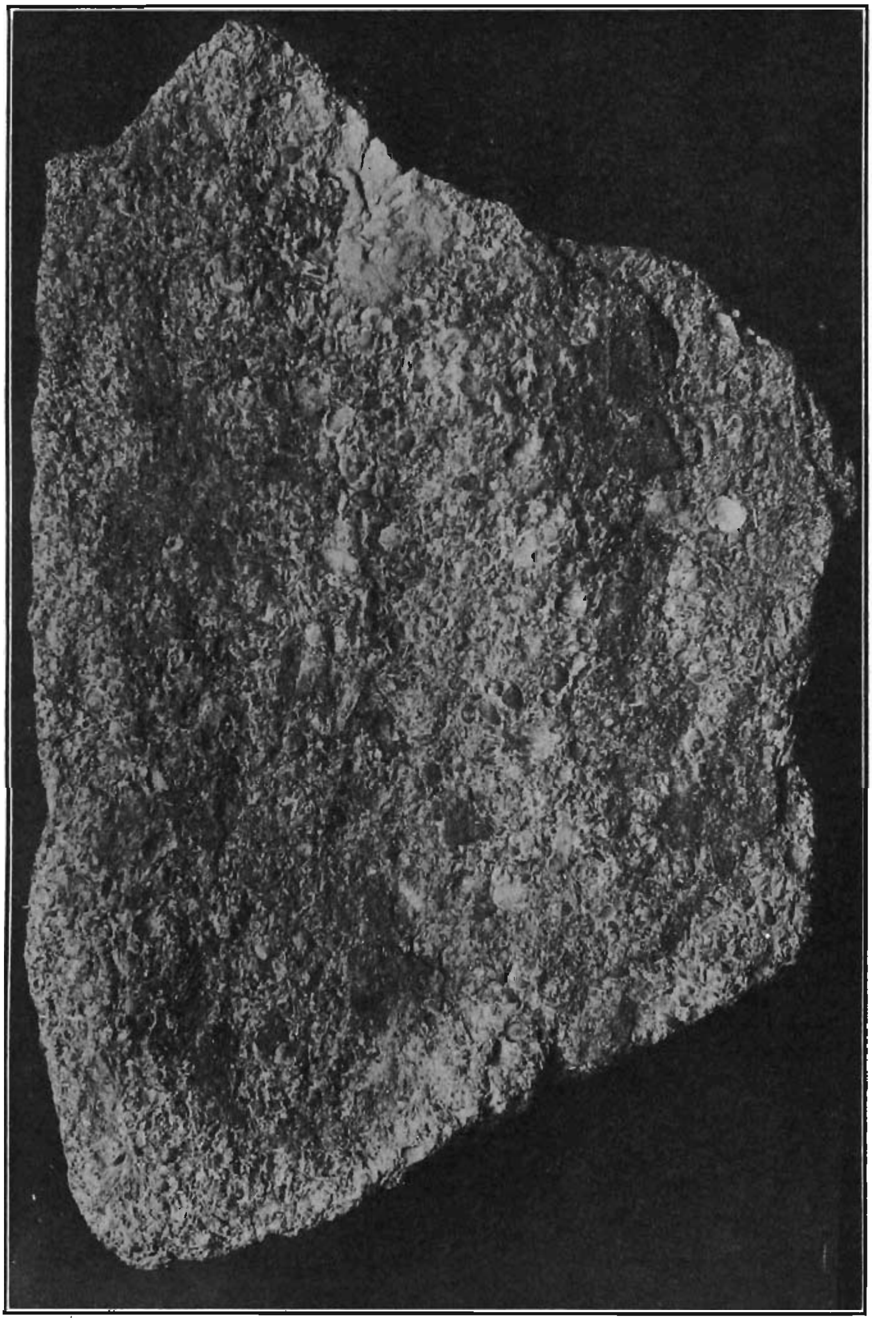


PLATE VII.

Graptolite slab from the Isotelus beds.

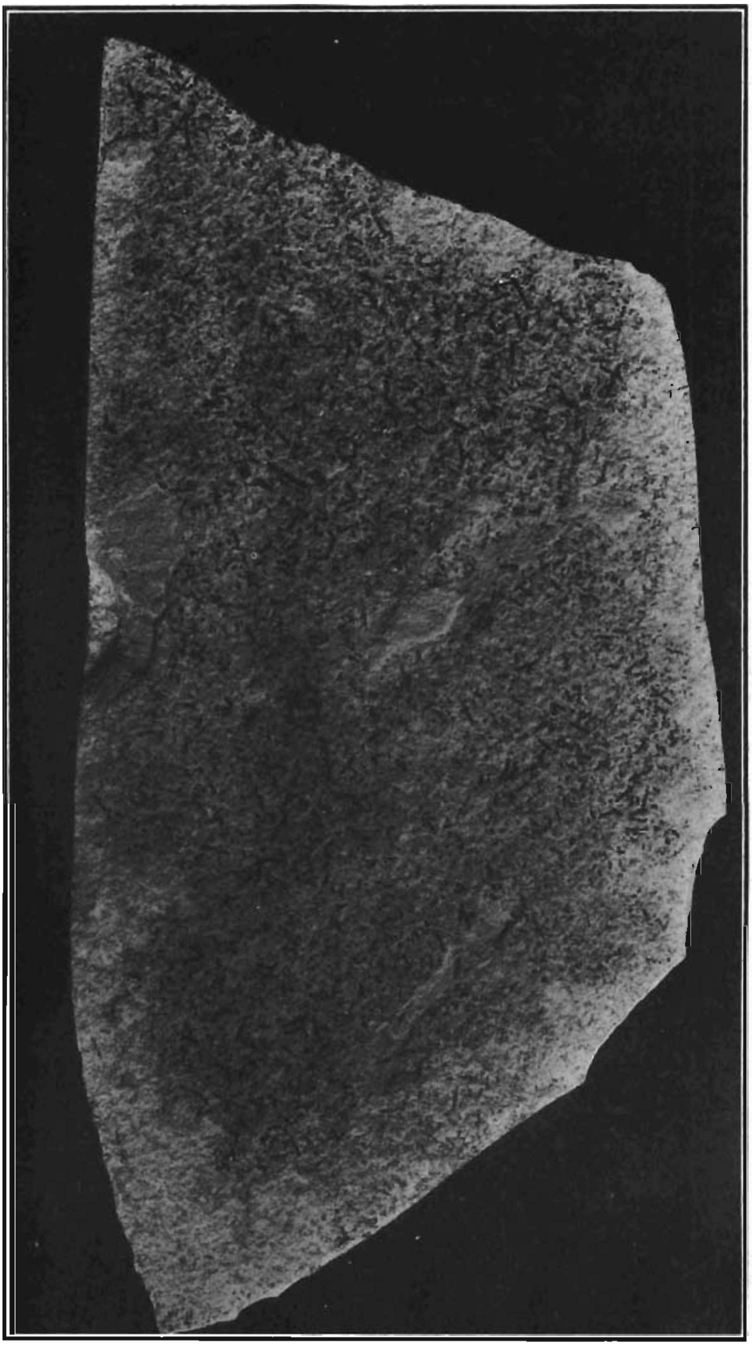


PLATE VIII.

Typical slab from the Isotelus beds.

PLATE IX.

Slab from the Vogdesia beds.

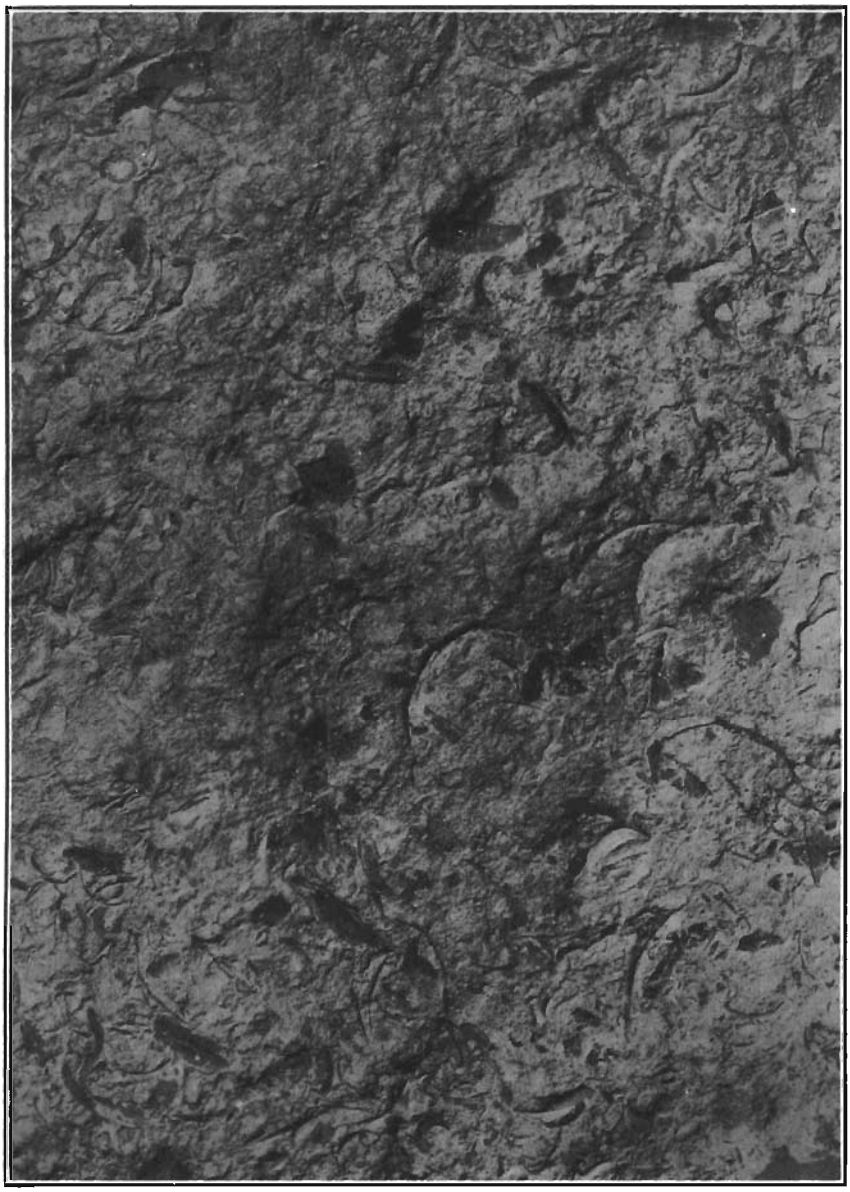


PLATE X.

Fossiliferous slab from the Upper Elgin beds.

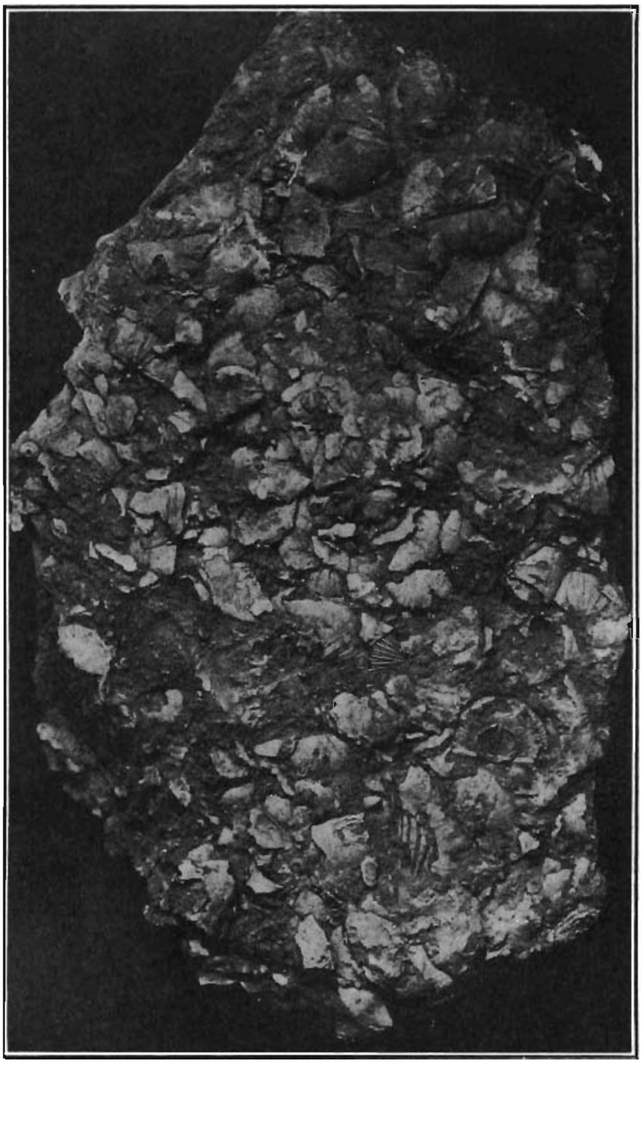


PLATE XI.

Fossiliferous slabs from the Cornulites zone of both areas.

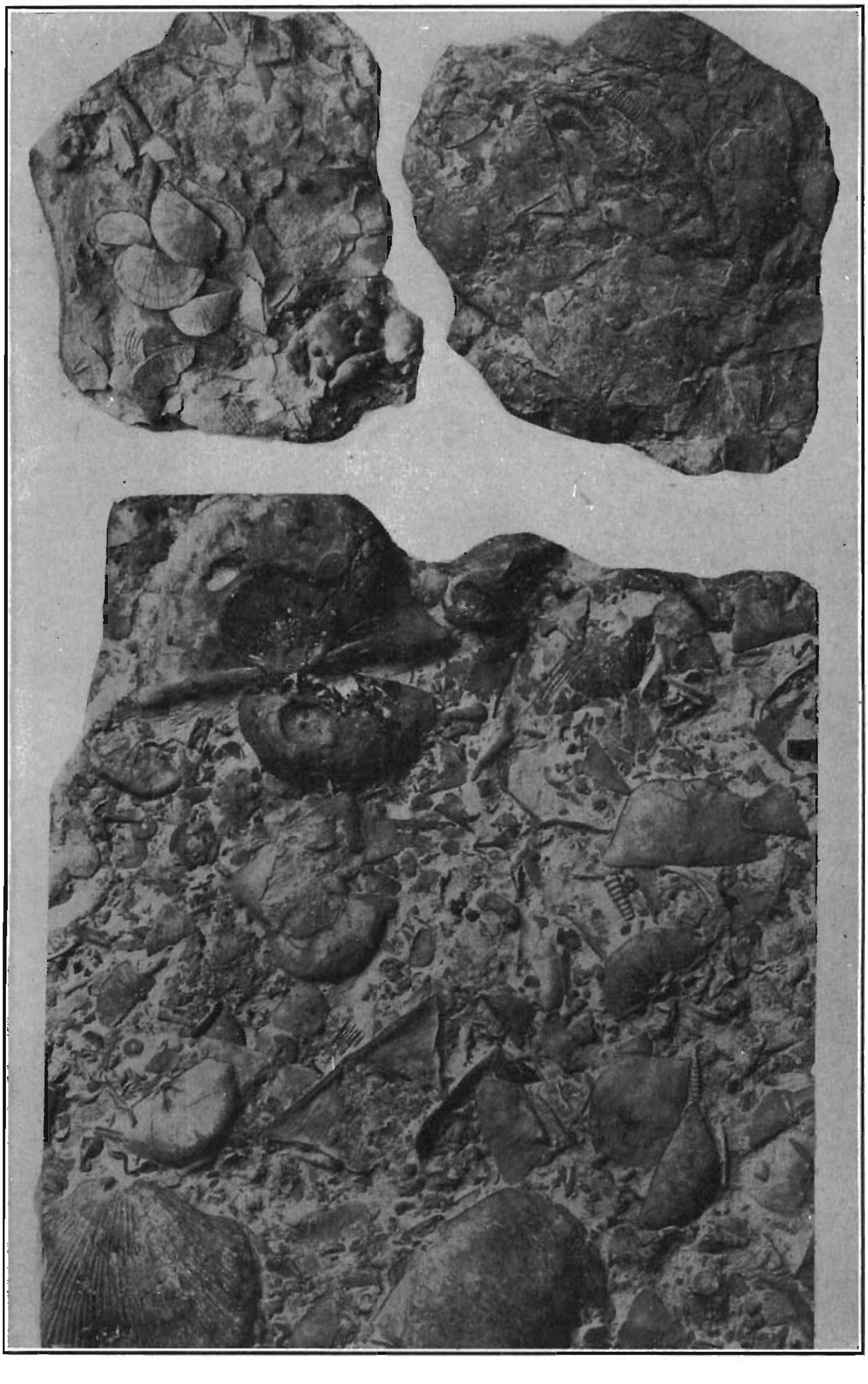
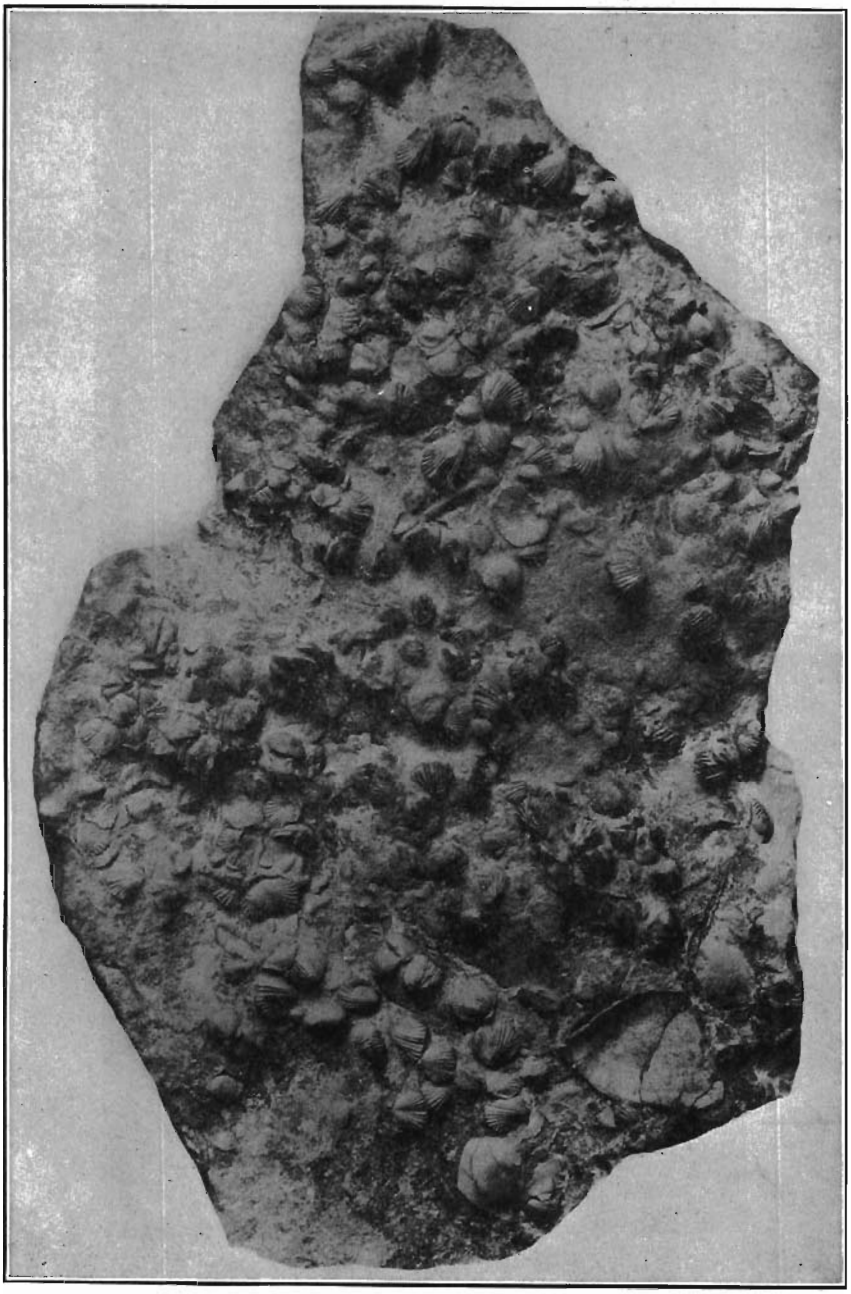
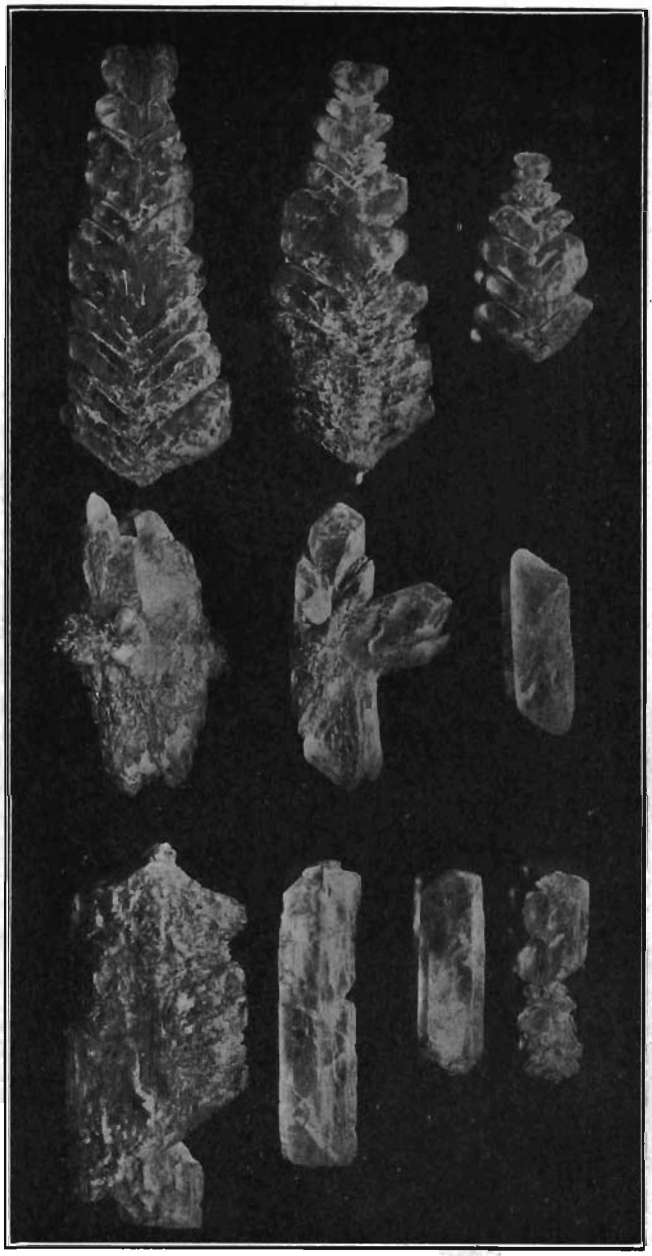


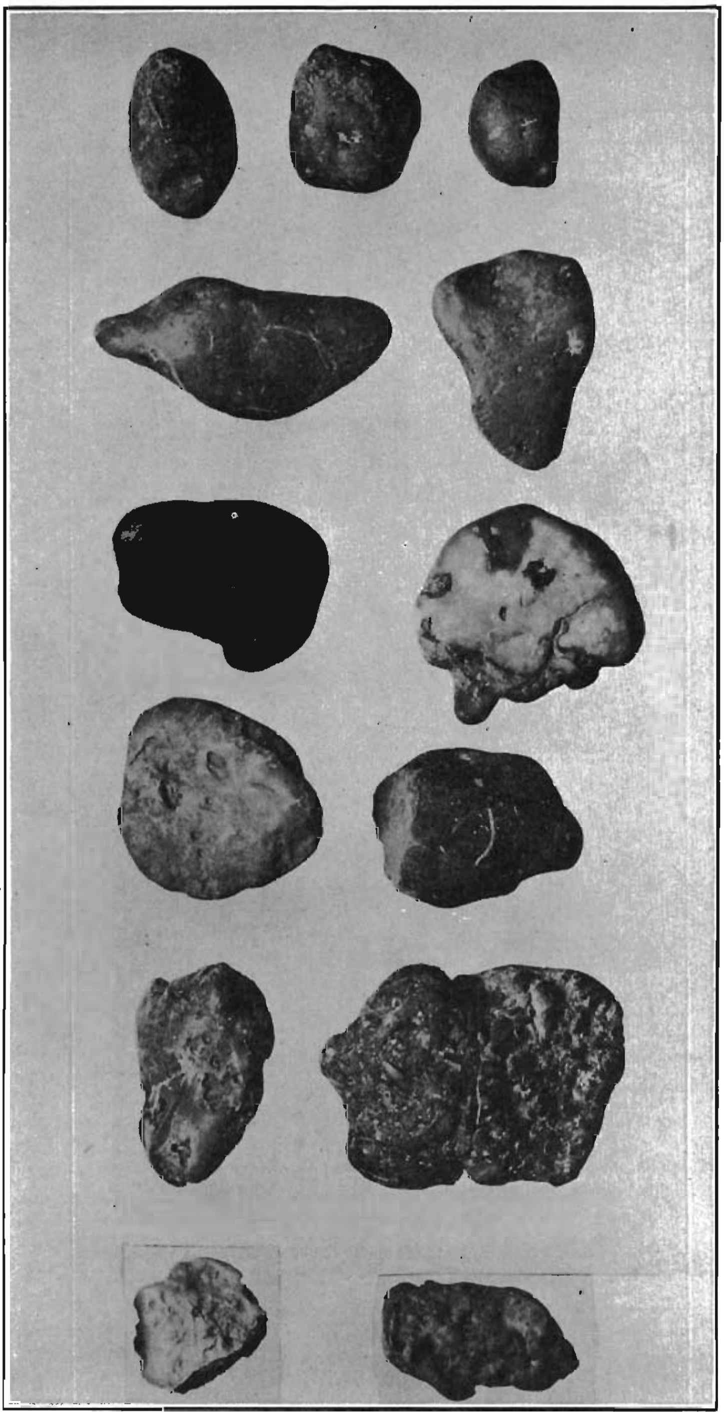
PLATE XII.

An unusual slab from the Cornulites zone of the Southeast Area.

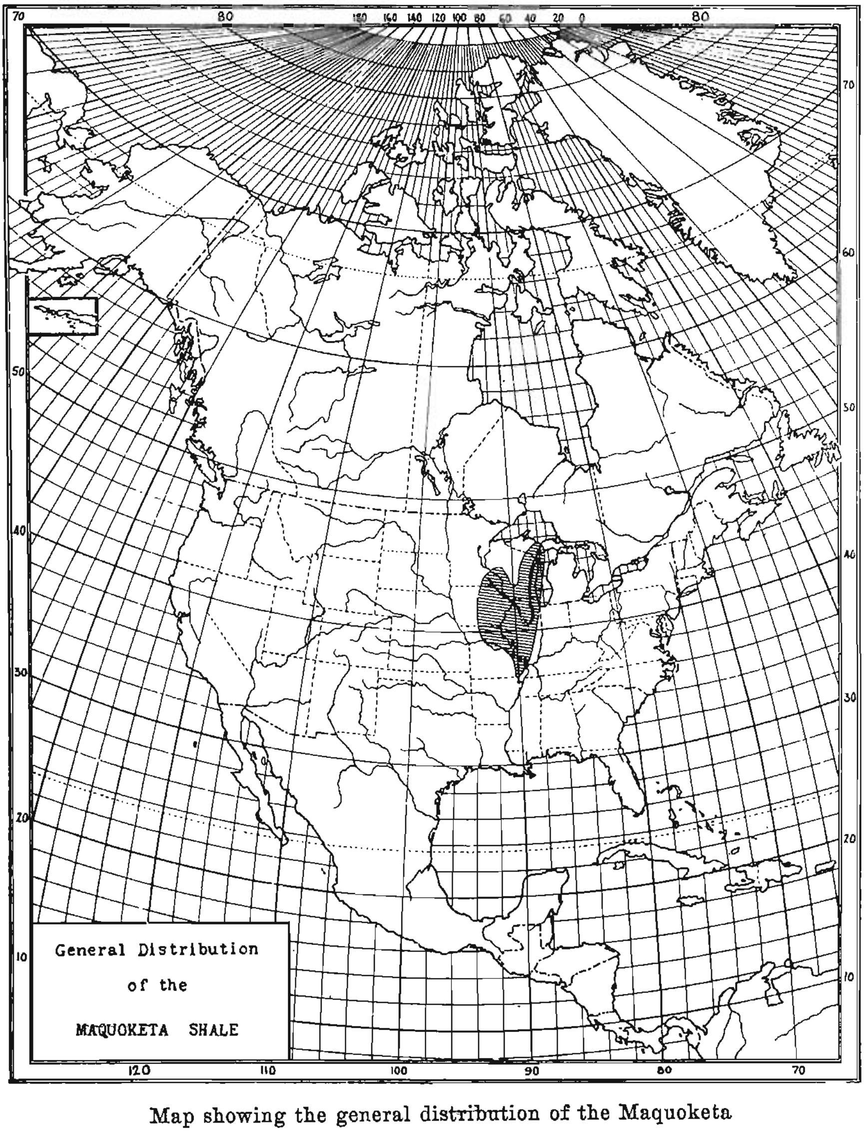




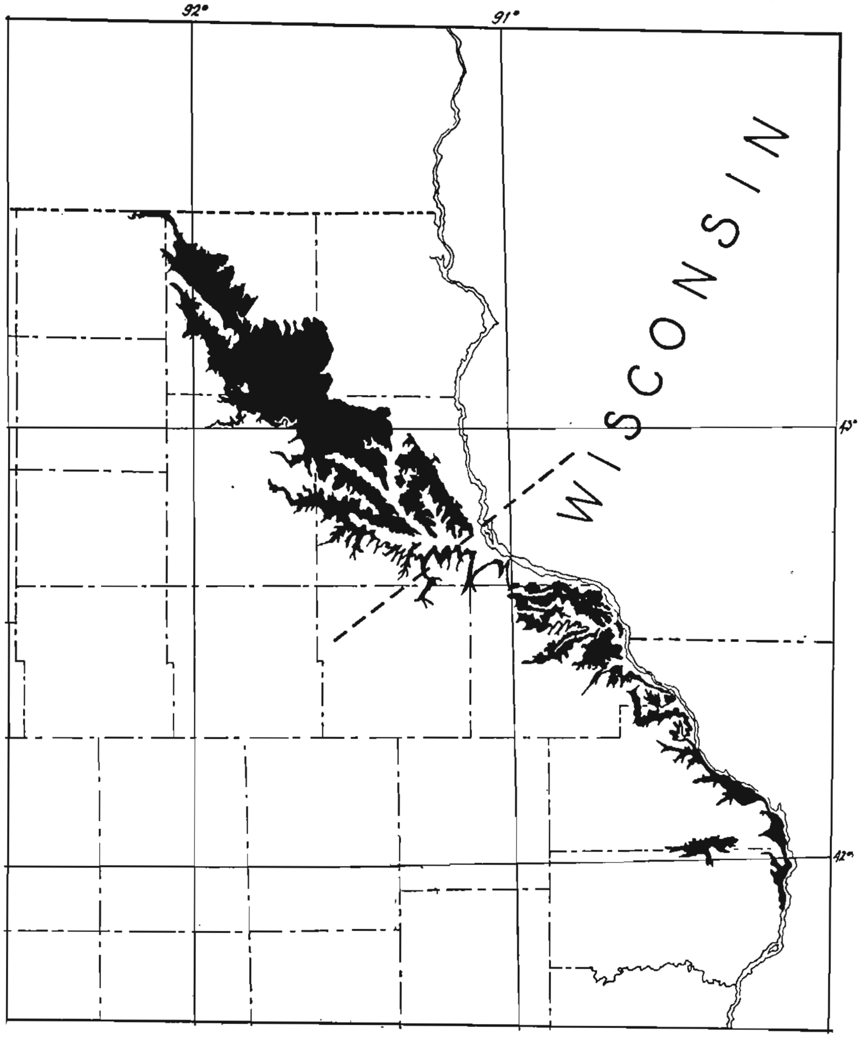
Selenite crystals from the Brainard shale



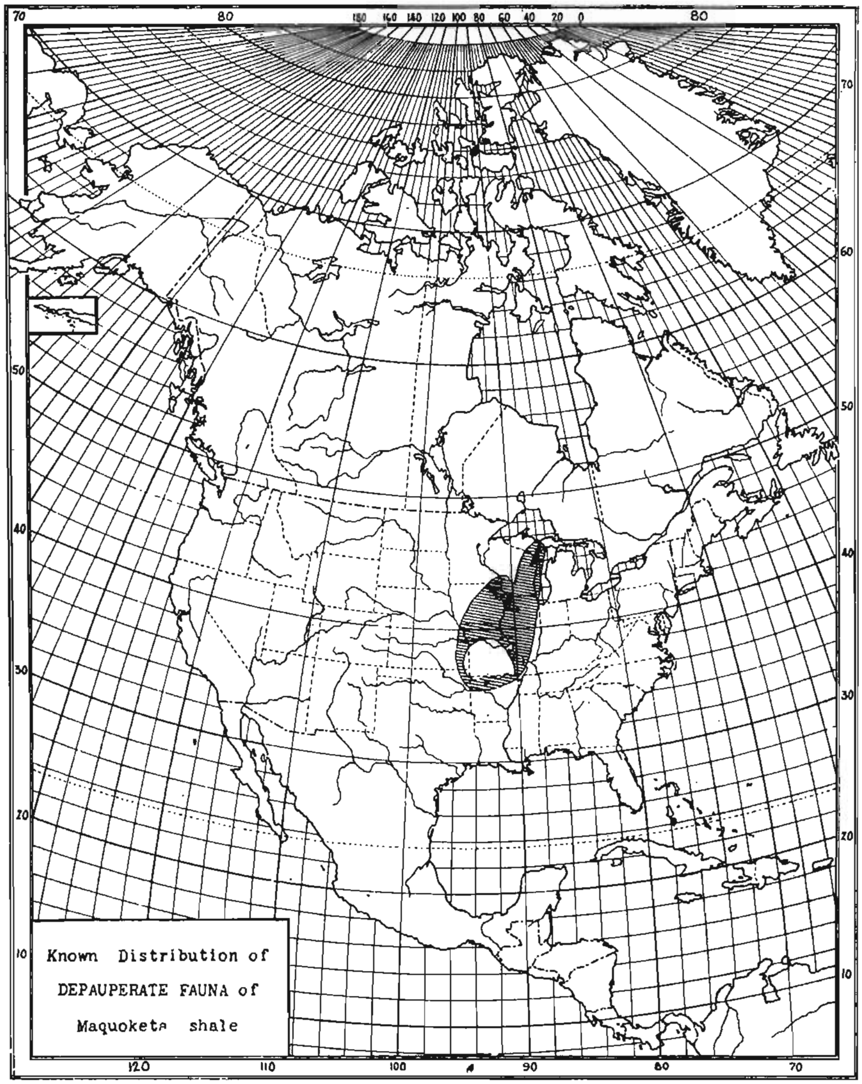
Pebbles from the Depauperate and Cornulites zones of the Maquoketa



Map showing the general distribution of the Maquoketa



Map of the distribution of the Maquoketa in Iowa, compiled from the county reports of the Iowa Survey, with slight modifications. The broken line indicates the approximate boundary between the Northwest Area and the Southeast Area.



Known distribution of the Depauperate fauna of the Maquoketa

Mineral Production in Iowa in 1927

by

JAMES H. LEES

MINERAL PRODUCTION IN 1927*

While the total valuation of the mineral output of 1927 was somewhat less than that of the preceding two years, yet in each branch but one there was an increase—in most cases a strongly marked one. The lone exception was the coal industry, in which the biennial strike caused a serious decline in output. It is evident that unless this industry can settle its differences in less mutually disastrous fashion it is doomed to eclipse by the eastern states, which have the edge on Iowa both in methods of mining and labor scales and in quality of output. The Geological Survey and the State University are making an effort to devise or adapt better methods of using Iowa coals in order to increase their output and use and to make such use more pleasant and economical. A start in this work has been made by the analysis of thirty-six typical coal samples from as many mines in the state. Further work will be done in the way of efforts to coke Iowa coal and to improve its quality by washing and in other ways.

The Iowa Railroad Commission furnishes the following data on shipments of mineral commodities originating in this state. Figures are for carloads.

Coal	26,083
Clay, gravel, sand and stone	71,584
Cement	28,764
Brick and artificial stone	14,561
Lime and plaster	6,987
Sewer pipe and drain tile	11,583

While some of these figures include reshipments of materials really produced outside the state, most of them represent materials actually extracted or made within the state's limits.

* Figures are compiled from data furnished by the U. S. Bureau of Mines and Bureau of the Census coöperating with the Iowa Geological Survey.

Mineral Production in Iowa, 1925 to 1927

Product	*Unit*	1925		1926		1927	
		quantity	*value*	*quantity*	*value*	*quantity*	*value*
Cement shipped	Bbl. of 376 lb.	4,856,849	$ 8,674,563	4,788,639	$ 8,167,341	5,661,234	$ 9,124,405
Clay wares			5,726,239		4,495,088		5,194,780
Coal	ton	4,714,843	14,807,000	4,625,487	14,214,000	2,949,622	9,304,000
Gypsum	ton	702,661	6,734,271	683,201	6,588,203	723,942	6,713,497
Limestone and lime	ton	808,288	904,669	944,371	952,141	1,278,056	1,267,033
Sand and gravel	ton	3,297,785	1,546,900	2,701,982	1,569,006	3,981,143	1,839,176
			$38,393,742		35,985,779		$33,442,891

CEMENT

Manufacture of Portland cement in Iowa was 10 per cent greater in 1927 than in 1926 and shipments increased 18 per cent in the later year. The Dewey Portland Cement Co. put its Davenport plant into operation in 1927. It has two 11 by 175 foot kilns and a daily clinker capacity of 3000 barrels or an annual finished cement capacity of 1,000,000 barrels. This increased the number of factories in the state to six, although the plant at Gilmore was not operated. The data regarding the industry in recent years are given herewith.

Production of Cement in Iowa and the United States

	1925	1926	1927
		Iowa	
Production, bbls.	4,648,145	4,925,811	5,415,144
Stock, Dec. 31, bbls.	1,479,670	1,616,842	1,370,752
Shipments, bbls.	4,856,849	4,788,639	5,661,234
Shipments, value	$8,674,563	8,167,341	9,124,405
Aver. fact. price per bbl.	$1.79	$1.71	$1.61
Consumption, bbls.	2,704,872	2,826,839	3,708,471
Consumption per capita, bbls.	1.08	1.17	1.53
Surplus production, bbls.	2,151,977	1,961,800	1,952,763
Annual capacity, bbls.	6,935,000	6,575,000	7,935,000
Coal used per bbl. cement, lb.			178
Coal used annually, tons			474,297
		United States	
Production, bbls.	161,685,901	164,530,170	173,206,513
Shipments, bbls.	157,295.212	162,187,090	171,864,728
Shipments, value	278,524,108	277,965,473	278,854,647
Average factory price, bbl.	$1.77	$1.71	$1.62
Consumption per capita, bbl.	1.38	1.37	1.44
Number plants active	138	140	153
Annual capacity, bbls.	193,558,000	215,300,000	227,080,000

CLAY WARES

The production of clay wares was somewhat in excess of that for 1926, although it was still below the output of the preceding years as far back as 1913. The manufacture of brick and sewer pipe was less in 1927 than in 1926, but other branches of the industry showed an increase. The tables show that 41 plants in 25 counties made brick of various kinds, that 28 plants in 19 counties made hollow building tile and that 40 plants in 24 counties made drain tile. Only four plants, in Keokuk, Polk and Webster counties, made sewer pipe, and other wares were produced in 13

Production of Clay Wares in Iowa in 1927

Counties	No. Producers	Brick (a)		Hollow ware (b)		Drain tile, sewer pipe, other products (c)		Total value
		Thous.	*Value*	*Tons*	*Value*	*Tons*	*Value*	
Appanoose (1), Henry (1), Jefferson (1), Lee (1), Van Buren (1)	5	1,960	$24,553	1,396	$ 7,205	3,743	$27,270	$59,028
Audubon (2), Pottawattamie (1), Union (1), Woodbury (2)	6	19,740	227,819	5,929	38,018	3,729	25,409	291,246
Benton (1), Grundy (1), Hardin (1), Tama (2)	5	1,398	23,792	(d)		1,195	13,112	36,904
Cerro Gordo	3	4,303	49,637	141,105	730,640	77,798	435,590	1,215,496
Dallas	3	3,384	42,142	35,460	211,411	16,249	104,081	357,633
Dubuque (1), Jackson (1), Johnson (1), Jones (1), Washington (1)	5	1,528	22,350	(e)		1,592	33,903	56,253
Fayette (1), Floyd (1), Franklin (1), Wright (1)	4	5,793	75,177	28,405	251,837	21,415	186,477	513,491
Jasper (1), Poweshiek (1), Story (2), Warren (1)	5	205	2,534	12,384	72,854	5,551	38,566	113,954
Keokuk	3	(d)				22,943	278,667	278,667
Mahaska (3), Wapello (1)	4	10,395	115,956	17,584	111,520	9,560	69,474	296,950
Polk	5	26,862	438,326	28,626	255,438	(f)		693,764
Webster	7	14,455	195,811	33,775	232,322	64,022	(g) 763,684	1,262,570
Total for 1927	55	90,053	1,219,695	293,061	1,766,653	251,000	2,208,432	5,194,780
Total for 1926	53	95,942	1,314,244	260,194	1,539,257		1,641,587	4,495,088

(a) Includes: Common brick, 51,885,000, value $564,425; Face brick, 23,720,000, value $397,945; Hollow brick, 394,000, value $4,742; Paving and other vitrified brick, 14,054,000, value $252,583.
(b) Includes: Partition, load-bearing, etc., 232,575 tons, value $1,363,354; Floor, arch, silo, etc., 60,486 tons, value $403,299.
(c) Includes: Drain tile, 176,404 tons, value $1,167,542; Sewer pipe, 65,322 tons, value $913,676; Flue lining, 3,925 tons, value $46,778; Wall coping, 972 tons, value $17,924; Segment blocks, pottery, other products, value $25,996; Raw clay, value $16,516.
(d) Included in Drain tile.
(e) Included in Brick.
(f) Included in Hollow ware.
(g) Includes other products, value $70,753.

plants in eight counties. Jackson had the only plant making earthenware in 1927—the Bellevue pottery.

The following table shows the production of the various items of the clay industry. Most counties are grouped by geographic proximity, where it is needful to conceal output of individual plants.

COAL

The year 1927 was not a very prosperous one for the coal industry, because of the disastrous strike which kept most of the mines closed during many months of the year. For this reason the output was the smallest since 1881, when it was 1,960,000 tons.

The following figures are of interest to show the classification of the coal that was loaded at mines for shipment in 1927. The total shipments of 2,147,000 tons were divided into: run-of-mine, 839,000, or 42.5 per cent of the amounts specified; prepared sizes, 816,000, or 41.3 per cent; slack or screenings, 321,000, or 16.2 per cent; not specified, 171,000.

Tons of coal and percentages mined by different methods were as follows: hand, 247,751, 8.4 per cent; shot off solid, 1,752,197, 59.4 per cent; machine cut, 867,885, 29.4 per cent; not specified, 81,789, 2.8 per cent.

The total production in Iowa from the earliest recorded output is 271,861,000 tons. The total for the United States is 14,428,639,000 tons bituminous and 3,642,992,000 Pennsylvania anthracite.

The table given below includes the essential data concerning the coal mining industry in 1927 and the totals for 1926.

Bituminous coal production in the United States was the lowest for five years, with the exception of 1924. It amounted to 517,763,000 tons, valued at the mines at $1,029,657,000, an average of $1.99. The active commercial mines numbered 7,011. Average number of days worked was 191; average number of employees was 593,918; average output per man—daily 4.55 tons, annual 872 tons. Iowa ranked seventeenth in tonnage and fifteenth in value of output.

Production, Value, Men Employed, Days Worked, and Output Per Man Per Day at Coal Mines in Iowa, in 1927[a]
(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 mine 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	3	....	3,860	....	3,860	$ 14,000	$3.63	16	2	18	206	1.04
Appanoose	49	259,716	55,830	1,067	316,613	1,008,000	3.18	1,920	143	2,063	69	2.21
Boone	8	216,413	62,752	4,426	283,591	1,247,000	4.40	849	58	907	135	2.31
Dallas	5	259,618	15,368	1,649	276,635	841,000	3.04	594	49	643	127	3.38
Davis, Jefferson, and Keokuk	3	....	6,183	....	6,183	23,000	3.72	17	2	19	138	2.36
Greene, Story, and Webster	3	....	13,186	....	13,186	45,000	3.41	32	5	37	184	1.94
Guthrie	4	....	7,534	....	7,534	31,000	4.11	22	4	26	192	1.51
Jasper	7	4,600	42,301	2,010	48,911	140,000	2.86	94	15	109	142	3.16
Mahaska	25	725	42,900	492	44,117	112,000	2.54	125	10	135	138	2.37
Marion	12	431,062	35,387	8,779	475,228	1,294,000	2.72	923	78	1,001	122	3.88
Monroe	11	411,291	23,108	10,574	444,973	1,327,000	2.98	1,285	93	1,378	102	3.18
Polk	15	257,040	326,906	10,609	594,555	1,851,000	3.11	1,105	94	1,199	158	3.14
Taylor	3	10,650	6,662	....	17,312	75,000	4.33	51	4	55	198	1.59
Van Buren	3	7,458	3,445	120	11,023	25,000	2.27	20	2	22	214	2.34
Wapello	14	1,193	54,262	370	55,825	174,000	3.12	119	13	132	169	2.51
Warren	3	112,229	5,828	8,950	127,007	396,000	3.12	354	32	386	99	3.32
Wayne	4	800	19,985	225	21,010	72,000	3.43	74	8	82	131	1.96
Other counties (Lucas and Page)	4	173,993	21,258	6,808	202,059	629,000	3.11	485	44	529	112	3.41
	176	2,146,788	746,755	56,079	2,949,622	9,304,000	3.15	8,085	656	8,741	114	2.96
Totals for 1926	184	3,791,893	740,136	93,458	4,625,487	14,214,000	3.07	8,192	677	8,869	183	

a The figures relate only to active mines of commercial size that produced coal in 1927. The number of such mines in Iowa was 183 in 1927; 193 in 1926; and 207 in 1925.

Methods of mining in 1927: The tonnage by hand was 247,751; shot off the solid, 1,752,197; cut by machines, 867,885; not specified, 81,789.

Size classes of commercial mines in 1927: There were 5 mines in Class 2 (100,000 to 200,000 tons) producing 27.8 per cent of the tonnage; 12 in Class 3 (50,000 to 100,000 tons) with 29.8 per cent; 41 in Class 4 (10,000 to 50,000 tons) with 30.0 per cent; and 125 in Class 5 (less than 10,000 tons) producing 12.4 per cent.

GYPSUM

Less gypsum was mined in 1927 than in 1926 or 1925, but at the same time more was sold, both crude and calcined, than in 1926, and more was sold calcined than in 1925. The industry evidently recovered from the slight setback of 1926 and is continuing its upward progress. This is evidently attributable to the diversification of products in the industry and their application to an increasingly wider range of usefulness.

The figures herewith tell the tale of progress.

Gypsum production in 1926 and 1927

	Iowa			
	1926		1927	
	tons	*value*	*tons*	*value*
Crude gypsum mined	802,910		792,159	
Sold crude—cement mills	125,956	$ 268,507	138,375	$ 384,024
for agriculture, etc.	3,847	28,347	1,262	7,677
Total sold crude	129,803	296,854	139,637	391,701
Sold calcined—stucco	30,355	236,804	18,743	115,267
neat and sanded plaster	402,169	3,007,628	379,702	2,711,701
plaster of paris (a)	4,278	41,047	6,624	51,317
wall and plaster board	87,395	2,605,745	104,851	2,603,155
partition tile (b)	18,481	171,621	55,516	487,844
insulating, etc.,	10,820	228,504	18,869	352,512
Total sold calcined	553,498	6,291,349	584,305	6,321,796
Total sold	683,201	6,588,203	723,942	6,713,497
	United States			
Plants active	59		60	
Total mined	5,623,441		5,346,888	
Sold crude	961,363	$2,509,885	965,371	$2,388,663
Sold calcined	4,015,974	44,211,334	3,912,211	39,785,791
Total sales	4,977,337	46,721,219	4,877,582	42,174,454

(a) Includes dental plaster, sales to plate glass works.
(b) Includes roofing tile, special tile or block.

LIMESTONE AND LIME

In the discussion of mineral production in 1926 the statement was made that the increase in output of stone constituted one of the bright spots in the mineral industry. That being true the spot seems to be brightening and broadening, in a general way at least, if we may judge from the data shown in the tables given below. Increases were shown in 1927 in the major branches of the industry, although some branches showed declines. These fluctuations may be seen by inspection of the appended summary.

Production of Stone and Lime, 1926 and 1927

Kind	1926		1927		Change	
	tons	*value*	*tons*	*value*	*tons*	*value*
Building	....	....	} 3,160	$ 4,869	—2,990	$ 2,292
Rubble	6,150	$ 7,161				
Riprap	91,150	87,756	124,400	123,321	+33,250	35,565
Concrete and road metal	627,290	599,490	866,590	839,463	+239,300	239,973
Ballast	75,190	69,670	105,140	93,773	+29,950	24,103
Flux	14,280	17,677	9,550	12,146	—4,730	5,531
Agriculture	114,700	101,620	163,680	156,069	+48,980	54,449
Sugar, lime, others	15,711	68,767	5,536	38,392	—10,175	30,375
	944,371	952,141	1,278,056	1,267,033	+333,685	315,892

Production of Limestone and Lime in 1927

Counties	No. Producers	Building stone, rubble, riprap*		Concrete, road metal		Other uses†		Total	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Black Hawk (2), Cerro Gordo (1)	3			64,939	$ 74,231	11,046	$ 5,970	76,005	$ 80,251
Clayton (2), Jackson (1)	3	83,314	$ 80,967			(a)		83,314	80,967
Dubuque	4	78,787	89,775	(a)				78,787	89,775
Hardin (1), Mitchell (1), Winneshiek (2)	4			111,720	114,342	53,315	57,797	165,035	172,139
Johnson (1), Linn (2)	3			132,576	196,947	15,000	16,500	147,576	213,447
Jones	3	10,325	10,892	11,760	11,760	5,544	4,139	27,629	26,791
Lee (2), Louisa (2)	4	8,112	10,111	59,238	91,444	(b)		67,350	101,455
Marshall	3			209,150	113,849	100,050	90,015	309,200	204,864
Scott	3	18,978	25,282	257,082	210,300	68,046	61,812	344,106	297,394
Total for 1927	30	127,560	128,190	866,590	839,463	283,906	299,380	1,278,056	1,267,033
Totals for 1926	27	97,300	94,917	627,290	599,490	219,781	257,734	944,371	952,141

* Includes: Building stone and rubble, 4 operators, 3,160 tons, value $4,869; Riprap, 12 operators, 124,400 tons, value $123,321.

† Includes: Railroad ballast, 4 operators, 105,140 tons, value $93,773; Flux, 4 operators, 9,550 tons, value $12,146; Agriculture, 17 operators, 163,680 tons, value $156,069; Sugar factories, lime, other uses, 4 operators, 5,536 tons, value $38,392.

(a) Included in Building stone, etc.

(b) Included in Concrete, etc.

Scott was the leading county, as for several years past, in both quantity and value. Marshall followed in second place, with Hardin, Johnson, Dubuque and Black Hawk holding the succeeding positions. The high place that Johnson and Linn counties held in values of output was due to the relatively higher prices received for road metal. Hardin has attained a prominent position in recent years since the Iowa Limestone Co. began producing crushed stone in large amounts. The total amount of crushed stone sold or used by producers in 1927 was 971,730 tons, valued at $932,236. This included concrete, road metal and railroad ballast, but not fluxing or agricultural stone.

Production of crushed stone in the United States amounted to 94,948,770 tons, valued at $97,474,267. In addition 21,666,070 tons of flux, valued at $15,985,525, and 2,206,470 tons of agricultural limestone, valued at $3,360,704, were prepared and sold. Total production of stone amounted to 136,345,260 tons, valued at $198,661,622.

SAND AND GRAVEL

The amount of sand produced and sold in Iowa in 1927 was 147,175 tons greater than that sold in 1926, but the amount received was $41,701 less. In the case of gravel, however, both output and value increased, the former by 1,131,986 tons or 83 per cent, the latter by $311,871, or 35 per cent. This increase is accounted for almost entirely by the greatly enlarged use of gravel for paving and roadmaking, an increase that amounted to 1,131,-638 tons, or 171 per cent. The total production also shows a gratifying increase—of 1,279,161 in tonnage and $270,170 in value—again owing very largely to road making activities. The summary table shows output and values of the various types of material, also the average prices received in 1927.

Summary of Sand and Gravel production, 1926 and 1927

	1926			1927			
Material	No. pits	*tons*	*value*	No. pits	*tons*	*value*	*Aver. price*
Sand							
Molding	5	27,843	$ 23,259	3	14,522	$ 11,231	$0.77
Structural	50	664,062	354,341	45	583,339	268,056	0.46
Paving	30	524,761	235,285	29	802,974	292,504	0.36
Cutting, grinding, blast	3	13,688	14,555				2.27
Engine	11	43,091	30,225	9	34,171	18,102	0.53
Filter	4	10,773	2,882	4	13,378	17,714	1.32
R. R. ballast	5	47,438	16,616	6	30,226	11,292	0.37
Other	7	17,551*a*	8,988	6	17,772*b*	25,551	
Total sand		1,349,207	686,151		1,496,382	644,450	
Gravel							
Structural	39	307,610	282,125	36	362,512	338,950	0.94
Paving	34	661,782	430,777	36	1,793,420	725,986	0.40
R. R. ballast	13	377,472	162,983	13	324,916	129,220	0.40
Other	4	5,911	6,970	3	3,913	570	0.15
Total gravel		1,352,775	882,855		2,484,761	1,194,726	
Total production		2,701,982	1,569,006		3,981,143	1,839,176	

a Includes fire or furnace sand and sand for miscellaneous uses.

b Includes cutting, grinding and blast sand, fire or furnace sand (Aver. price, $0.78 per ton), other sands (Aver. price, $0.30 per ton).

The detailed tables showing production in the different counties indicate that Polk county yielded to Muscatine county the leadership she held the previous year. This change again came about through the great increase in production of roadmaking sand and gravel in Muscatine county, for the output of structural material was much greater in Polk than in Muscatine. These statements do not include the noncommercial production of gravel by the State Highway Commission. Other leading counties were, in order of production, Sac, Cerro Gordo, Linn, Sioux, Cherokee, Johnson and Jackson. Each raised and sold over one hundred thousand tons.

Production the country over amounted to 197,454,269 tons, valued at $115,529,786, the largest for any year. The leading state was New York, with an output amounting to 19,896,766 tons. Iowa's rank was thirteenth. The distribution of the output was as follows:

Sand and Gravel sold or used by producers in the United States in 1927

	1927		
	Short tons	*Value*	*Average*
Sand:			
Glass	2,171,693	$ 3,257,790	$1.50
Molding	4,194,975	4,458,508	1.06
Building	40,737,377	22,198,767	.54
Paving	35,606,622	17,767,491	.50
Grinding and polishing	1,686,762	2,193,690	1.30
Fire or furnace	410,801	452,835	1.10
Engine	2,618,890	1,640,736	.63
Filter	74,674	155,137	2.08
Other	6,086,545	2,166,444	.36
	93,588,339	54,291,398	
Gravel:			
Building	30,432,031	21,947,666	.72
Paving	44,891,975	29,887,365	.67
Railroad ballast	28,541,924	9,403,357	.33
	103,865,930	61,238,388	
Grand total	197,454,269	115,529,786	.59
Grand total for 1926	183,100,818	111,338,701	.61

Production of Sand and Gravel in 1927—Sand

Counties	Producers	Structural sand		Paving and other sand *a*		Total sand	
		tons	*value*	*tons*	*value*	*tons*	*value*
Black Hawk (1), Butler (2), Fayette (1)	4	40,175	$ 24,040	*b*		40,175	$ 24,040
Boone (1), Marshall (2)	3	27,818	14,234	*b*		27,818	14,234
Buena Vista (0), Clay (2), Dickinson (0), Sac (1)	3	36,084	12,802	*b*		36,084	12,802
Cerro Gordo (2), Floyd (1), Franklin (1), Hardin (1)	5	38,504	18,873	88,565	$ 43,165	127,069	62,038
Cherokee (1), Plymouth (2)	3	*c*		65,833	22,496	65,833	22,496
Clayton (2), Dubuque (2), Jackson (1)	5	30,460	9,431	42,628	26,546	73,088	35,977
Clinton (1), Lee (2), Scott (2)	5	43,082	21,370	38,823	21,052	81,905	42,422
Dallas (0), Marion (0), Wapello (1)	1	*d*		*d*		*d*	
Emmet (1), Humboldt (1), Palo Alto (1)	3	26,748	9,911	....	....	26,748	9,911
Johnson (2), Linn (2)	4	66,954	44,392	207,370	129,410	274,324	153,802
Muscatine	6	46,490	25,142	270,138	73,046	316,628	98,188
Polk	8	172,892	61,305	82,136	24,881	255,028	86,186
Sioux	5	40,120	19,560	43,975	20,550	84,095	40,110
Story (0), Webster (1)	1	*d*		*d*		*d*	
Totals	56	583,339	268,056	913,043	376,394	1,496,382	644,450
Totals for 1926	70	664,062	354,341	685,145	331,810	1,349,207	686,151

a Includes: Molding, paving and roadmaking, cutting, grinding and blast, fire or furnace, engine, filter, railroad ballast, and other sands.

b Included with structural sand.

c Included with paving sand.

d Included with paving gravel.

Production of Sand and Gravel in 1927—Gravel

Counties	Producers	Structural gravel		Paving and other gravel e		Total sand and gravel		Total quantity washed	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Black Hawk (1), Butler (1), Fayette (1)	3	11,161	$ 14,725	*f*		51,336	$ 38,765	47,961	$ 37,515
Boone (1), Marshall (2)	3	20,470	13,044	*f*		49,428	27,657	35,878	23,672
Buena Vista (1), Clay (1), Dickinson (1), Sac (2)	5	*d*		319,684	$134,344	355,768	147,166	132,417	82,245
Cerro Gordo (2), Floyd (0), Franklin (0), Hardin (1)	3	*d*		105,037	112,176	232,106	174,212	228,102	173,512
Cherokee (3), Plymouth (1)	4	*d*		121,298	67,413	187,131	90,309	94,331	57,423
Clayton (0), Dubuque (2), Jackson (1)	3	26,193	19,212	73,992	48,464	152,916	87,907	120,993	70,683
Clinton (2), Lee (1), Scott (2)	5	15,505	16,915	21,429	15,255	118,839	74,592	25,860	11,885
Dallas (1), Marion (1), Wapello (1)	3	*d*		123,774	71,890	123,774	71,890	123,774	71,890
Emmet (1), Humboldt (1), Palo Alto (2)	4	10,944	13,761	81,920	12,310	119,612	35,982	36,248	22,296
Johnson (2), Linn (0)	2	*b*		*c*		274,324	153,802	274,324	153,802
Muscatine	6	57,927	55,073	332,724	127,426	707,169	279,687	696,531	271,945
Polk	7	83,763	109,942	85,057	68,816	427,648	264,944	404,179	253,111
Sioux	3	33,600	20,525	35,250	19,500	152,935	80,135	139,950	76,335
Story (1), Webster (2)	3	*d*		62,800	12,900	62,800	12,900	8,000	6,725
Highway Comm.	1	....	....	945,000	283,500	945,000	283,500	....	....
Totals	55	362,512	338,950	2,122,249	855,776	3,981,143	1,839,176	2,419,280	1,340,037
Totals for 1926	63	307,610	282,125	1,045,165	600,730	2,701,982	1,569,006	2,294,289	1,444,995

b Included with structural sand.
c Included with paving sand.
d Included with paving gravel.
e Includes: Paving and roadmaking, railroad ballast, and other gravel.
f Included with structural gravel.

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