THE STRATIGRAPHY AND PALEONTOLOGY

of the

MAQUOKETA SHALE OF IOWA

PART I

by

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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 acknowleged 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.

* 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

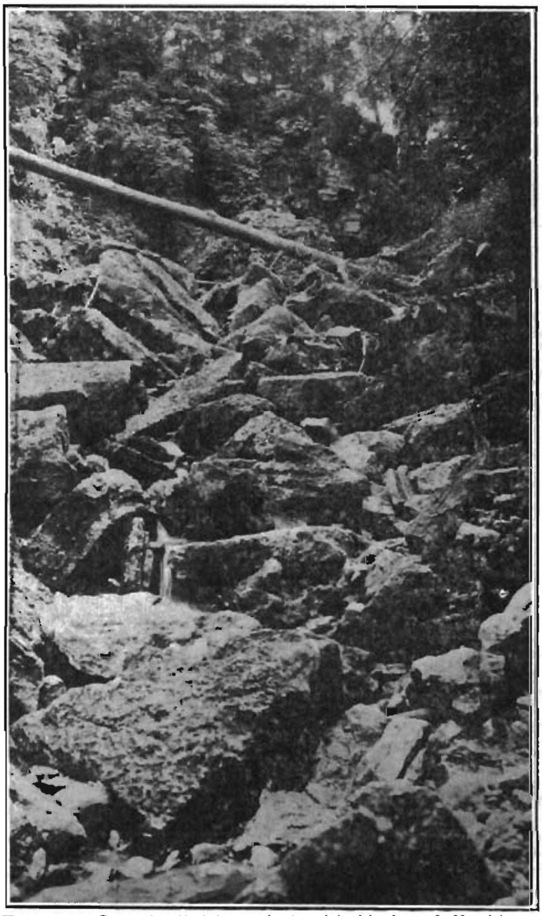

FIG. 64.—Cascade Gulch choked with blocks of Hopkinton dolomite. Southwest quarter, section 17, Dover township, Fayette county, Iowa. Photo by Thomas.

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 Tren ton 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,

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* 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:

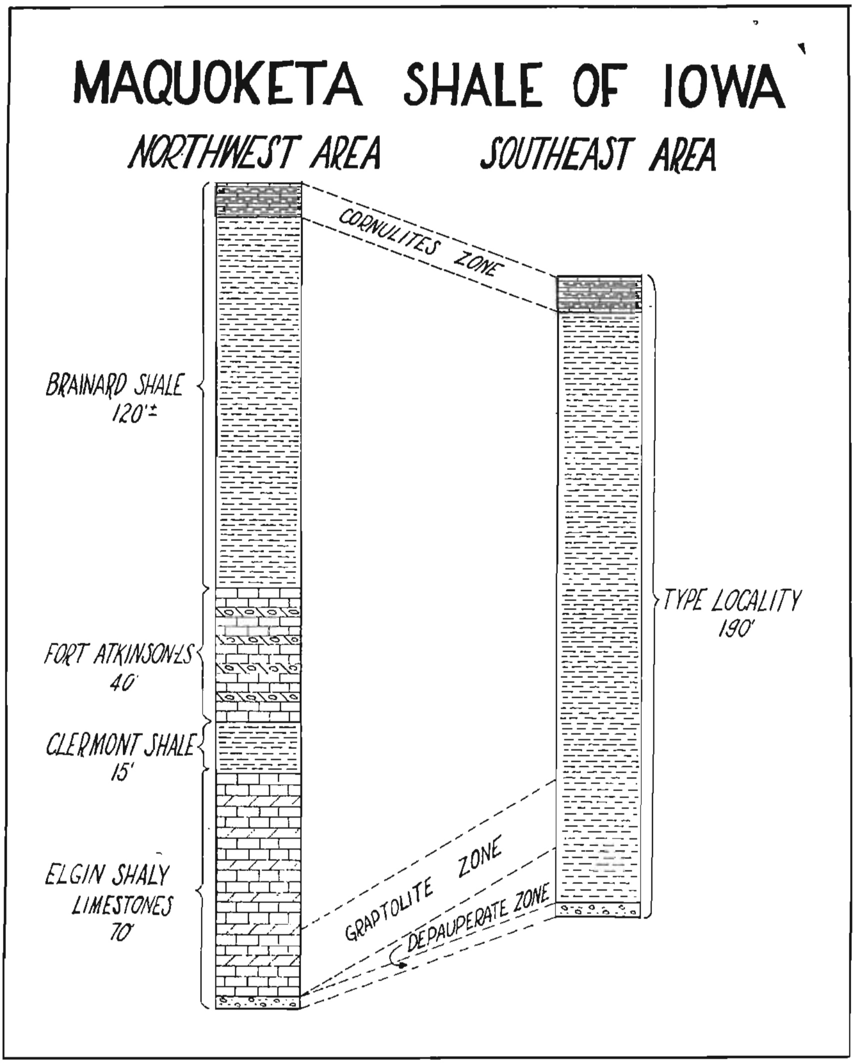

FIG. 67.—Columnar sections of the Maquoketa in the Northwest and Southeast Areas in Iowa.

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.

* 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.

Alexandrian limestone		FEET
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

* 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

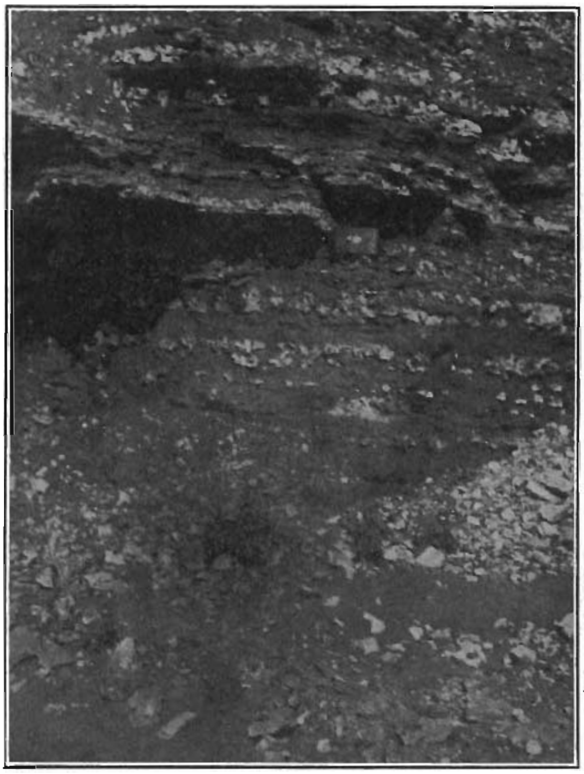

FIG. 69.—Another view of the cherty beds Same location as figure 68.

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

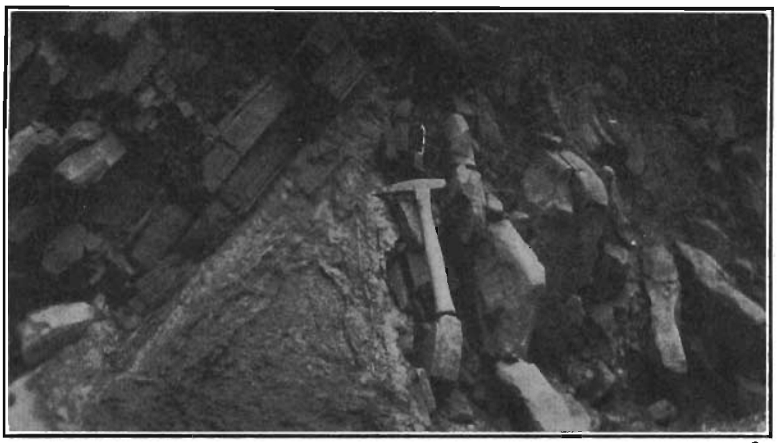

FIG. 70.—Small slump fold involving the Maquoketa shale and the overlying Edgewood beds. Southwest quarter, section 14, Prairie Spring township, Jackson county, Iowa.

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):

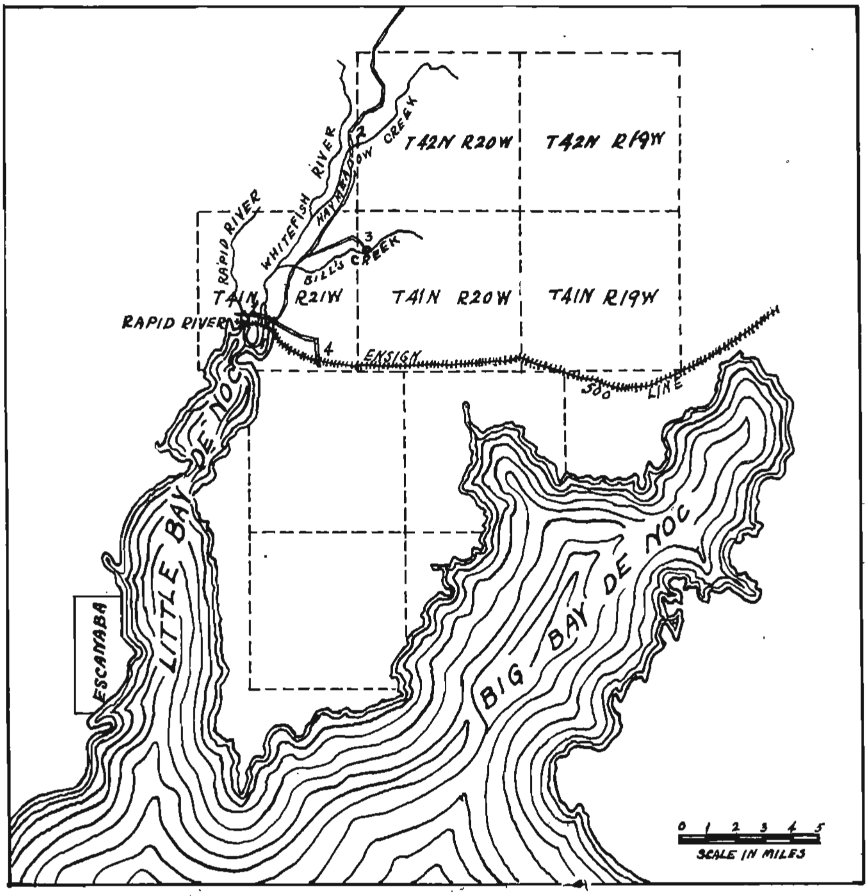

FIG. 71.—Map of a part of the Upper Peninsula of Michigan showing localities visited. (Outline after Hussey.)

"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.

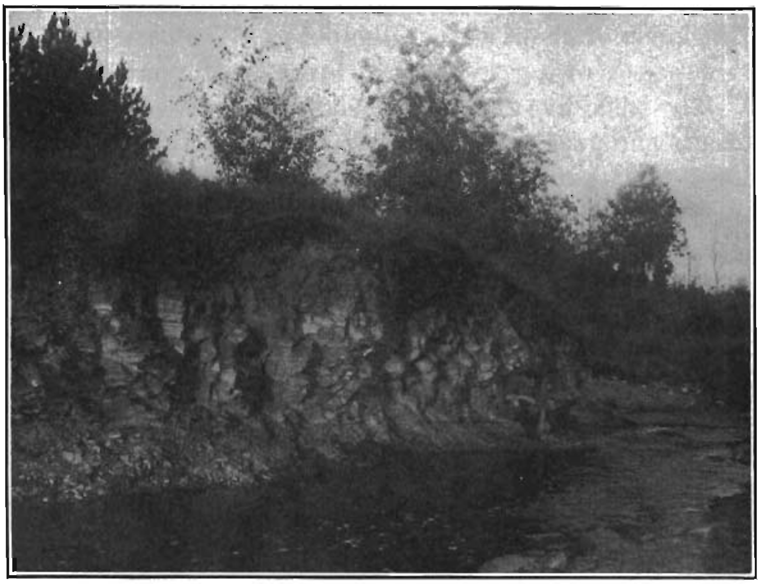

FIG. 72.—Maquoketa section on Bill's creek; base of the exposed section. Upper Peninsula of Michigan.

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.	Cyclora hoffmanni Miller
Dalmanella sp.	Cyclora minuta Hall
Zygospira modesta Hall	Cyclora parvula (Hall)
Ctenodonta sp.	Hyolithes parviusculus (Hall) (same as Hyolithes versaillesensis Miller and Faber ?)
Clidophorus faberi Miller	Coleolus iowensis James (Hyolithes ? dubius Miller and Faber)
Clidophorus fabula (Hall)	
Microceras inornatum Hall	
Cyclora depressa Ulrich	

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.	Sceptropora facula Ulrich
Anaphragma mirabile Ulrich	Dicranopora fragilis (Billings)
Helopora elegans Ulrich	

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

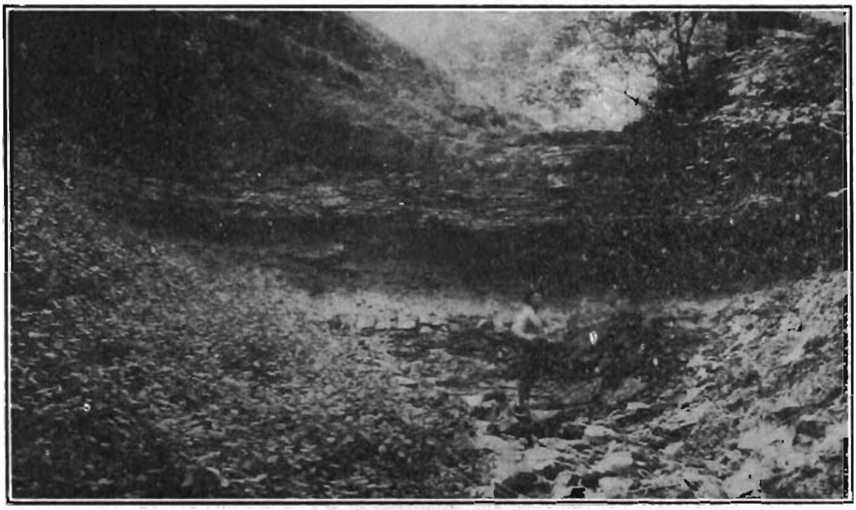

FIG. 75.—Patterson's spring, western half northwest quarter, section 20, Pleasant Valley township, Fayette county, Iowa. An excellent exposure of the Cornulites zone of the Northwest Area. Photo by Thomas.

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.

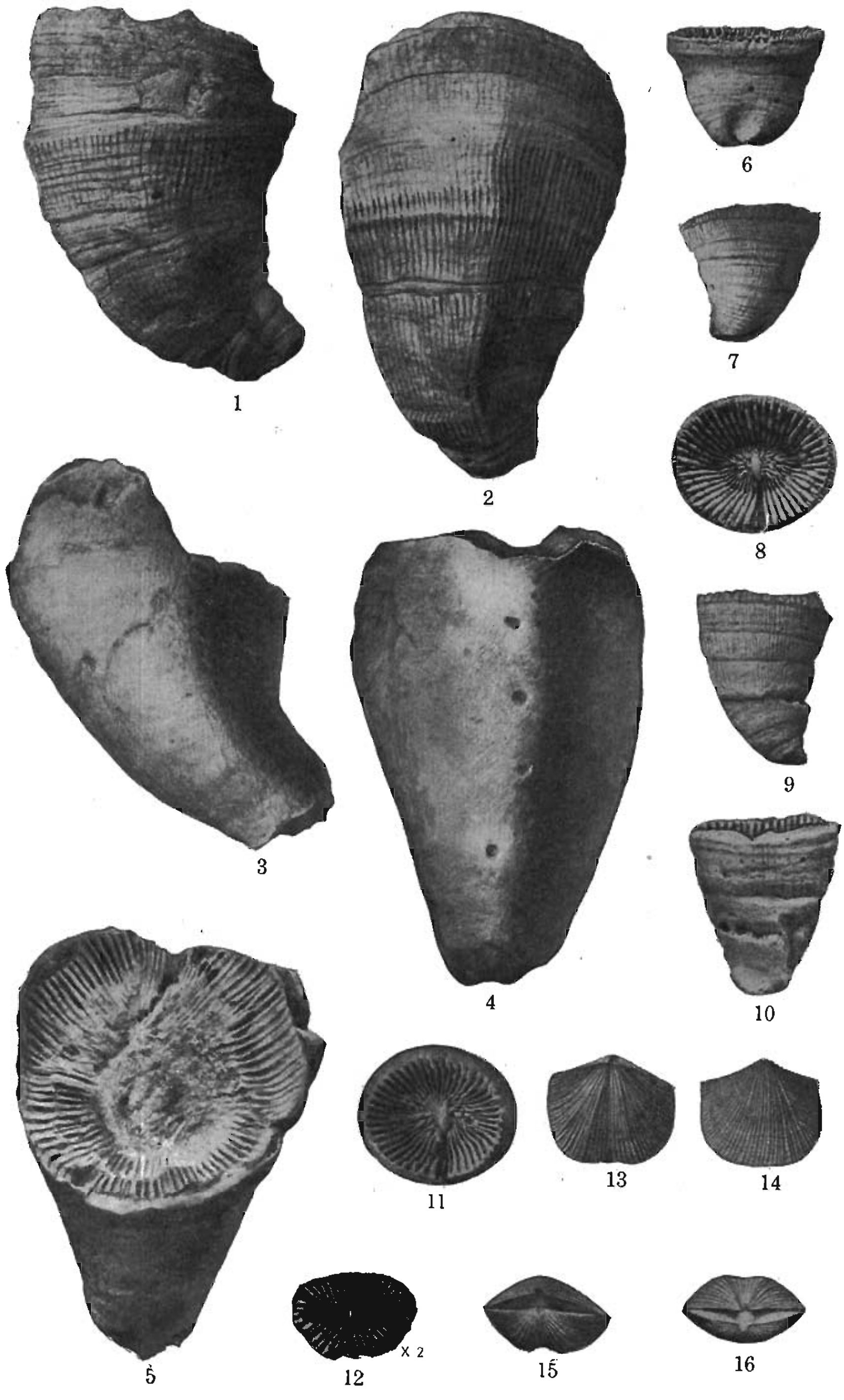
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PLATE V.

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.

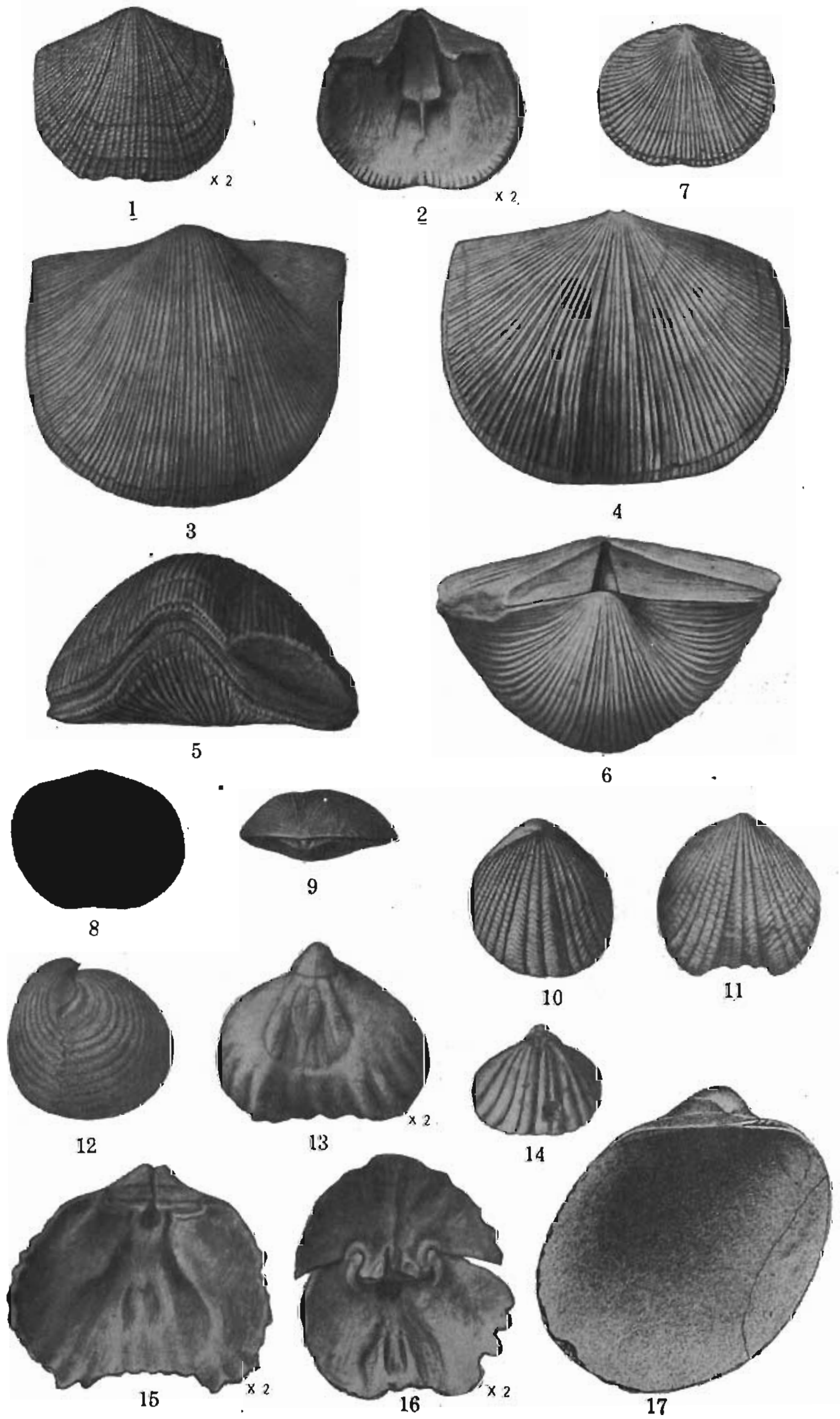
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PLATE VI.

Fossiliferous slab from the Depauperate zone.

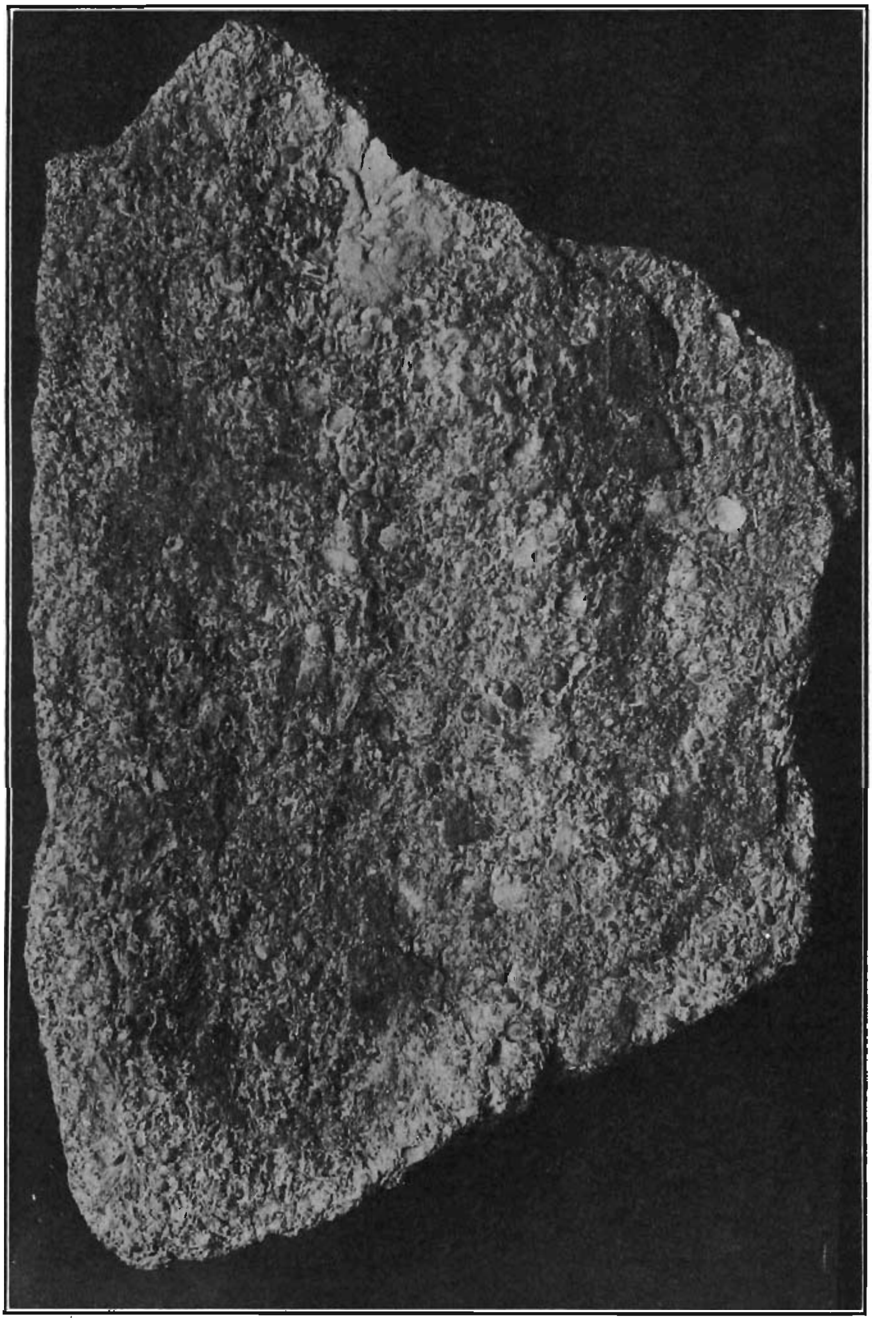


PLATE VII.

Graptolite slab from the Isotelus beds.

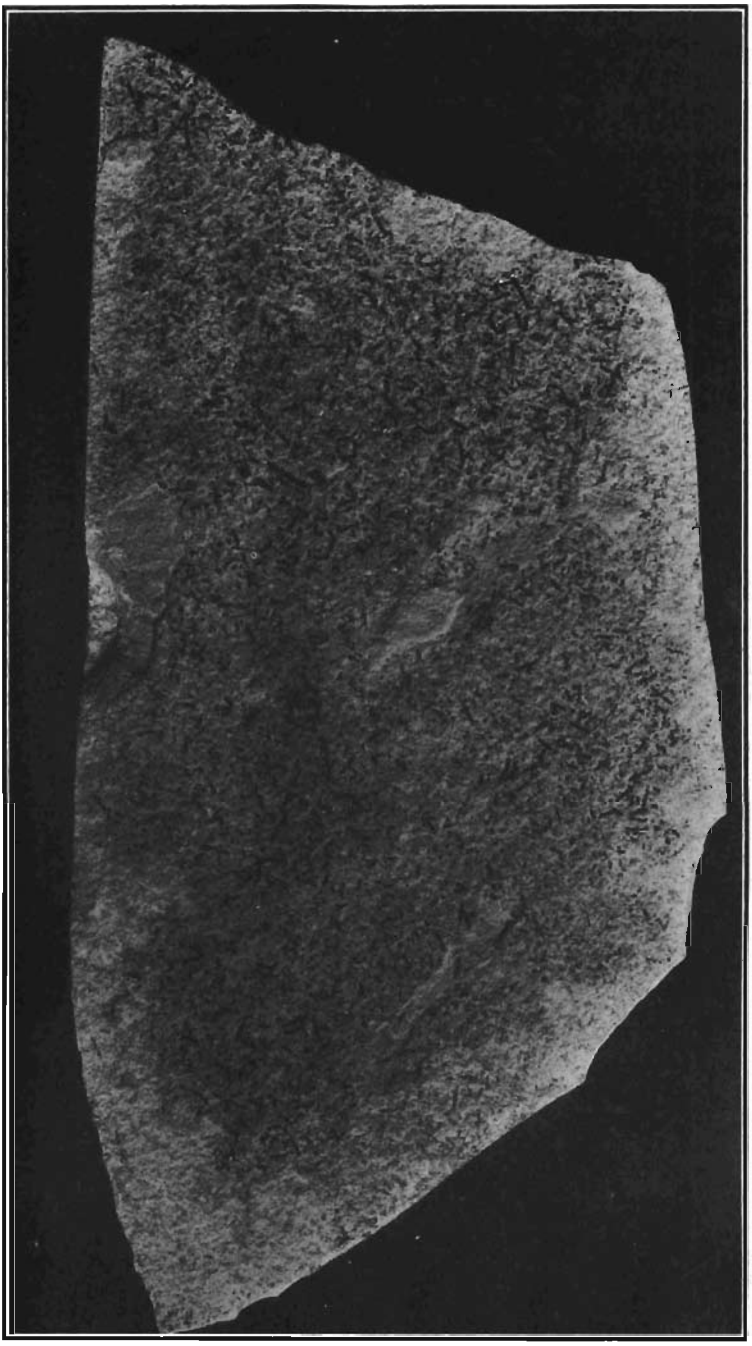


PLATE VIII.

Typical slab from the Isotelus beds.

PLATE IX.

Slab from the Vogdesia beds.

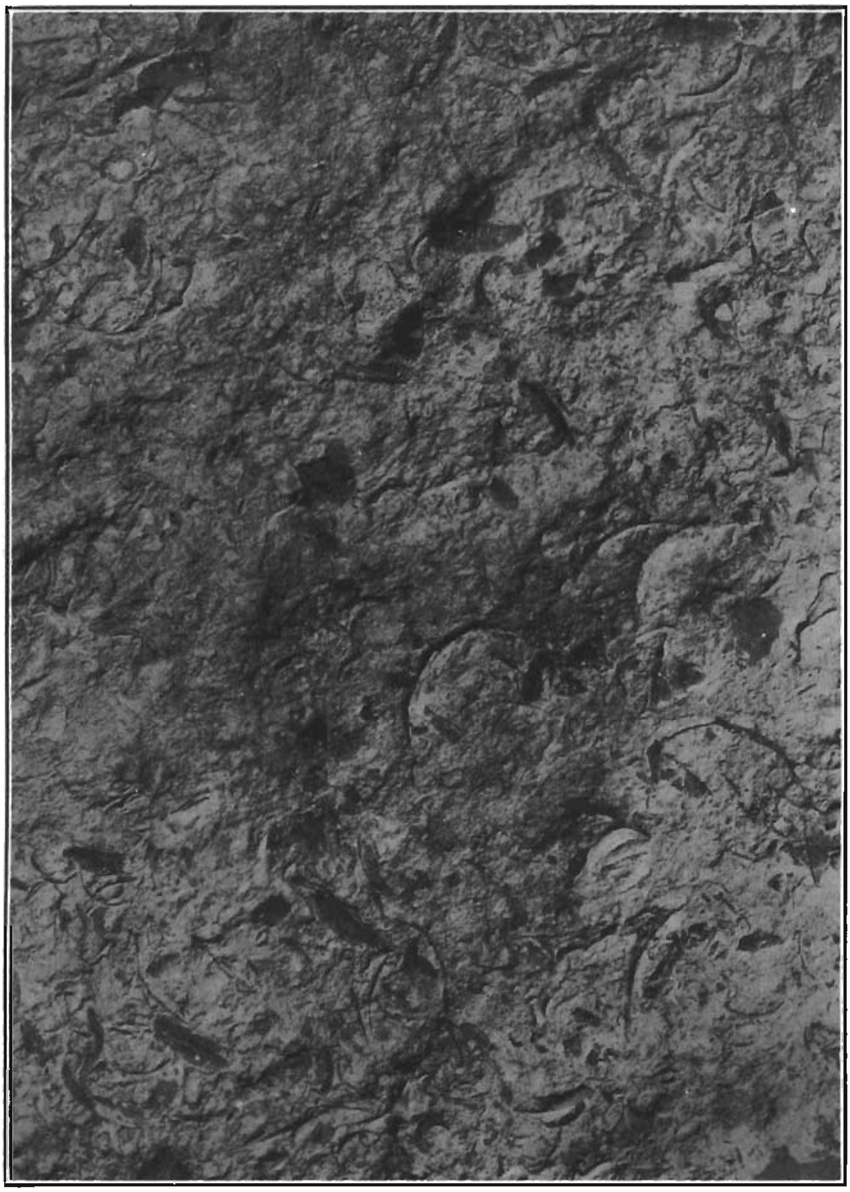


PLATE X.

Fossiliferous slab from the Upper Elgin beds.

PLATE XI.

Fossiliferous slabs from the Cornulites zone of both areas.

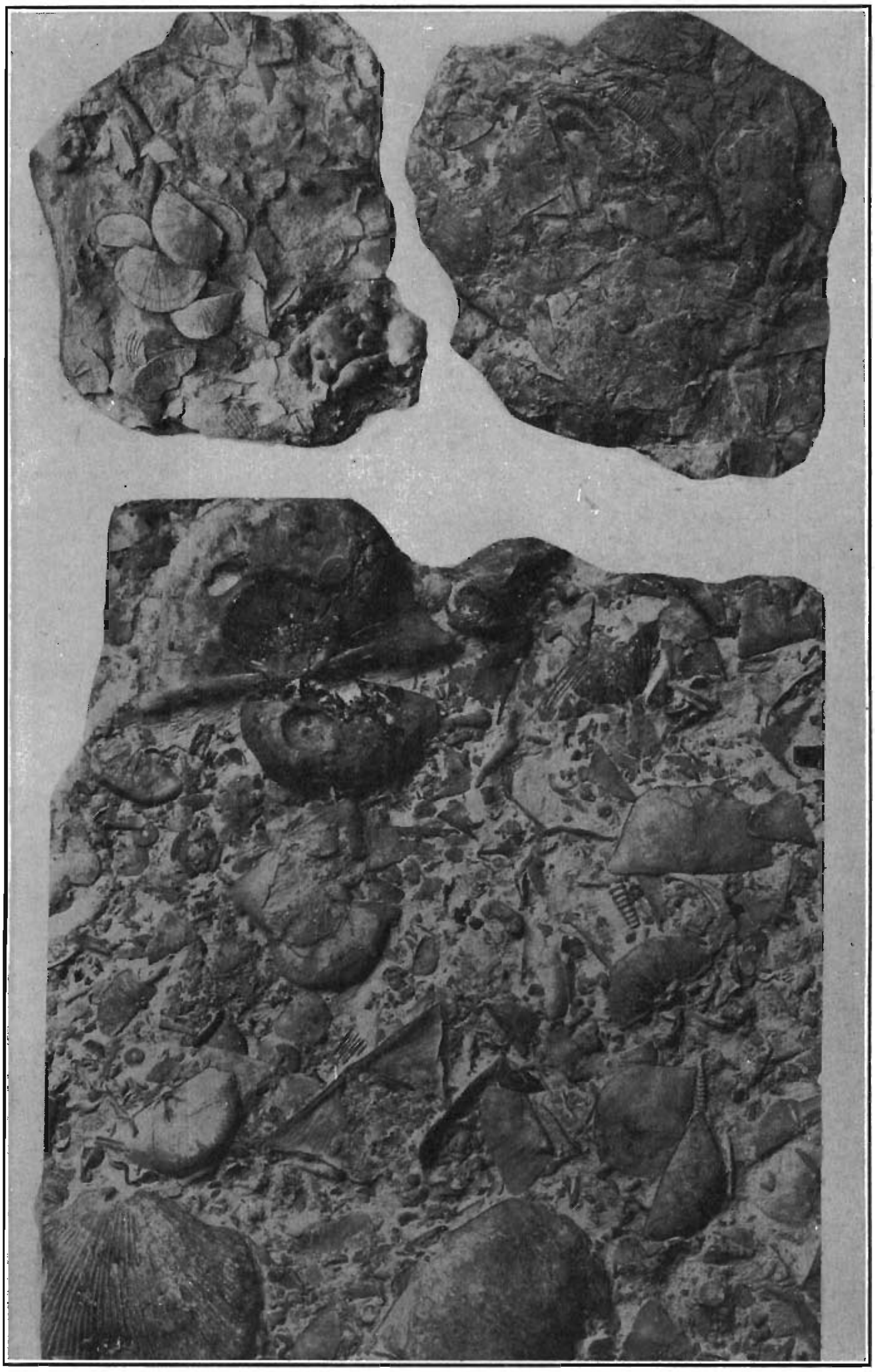
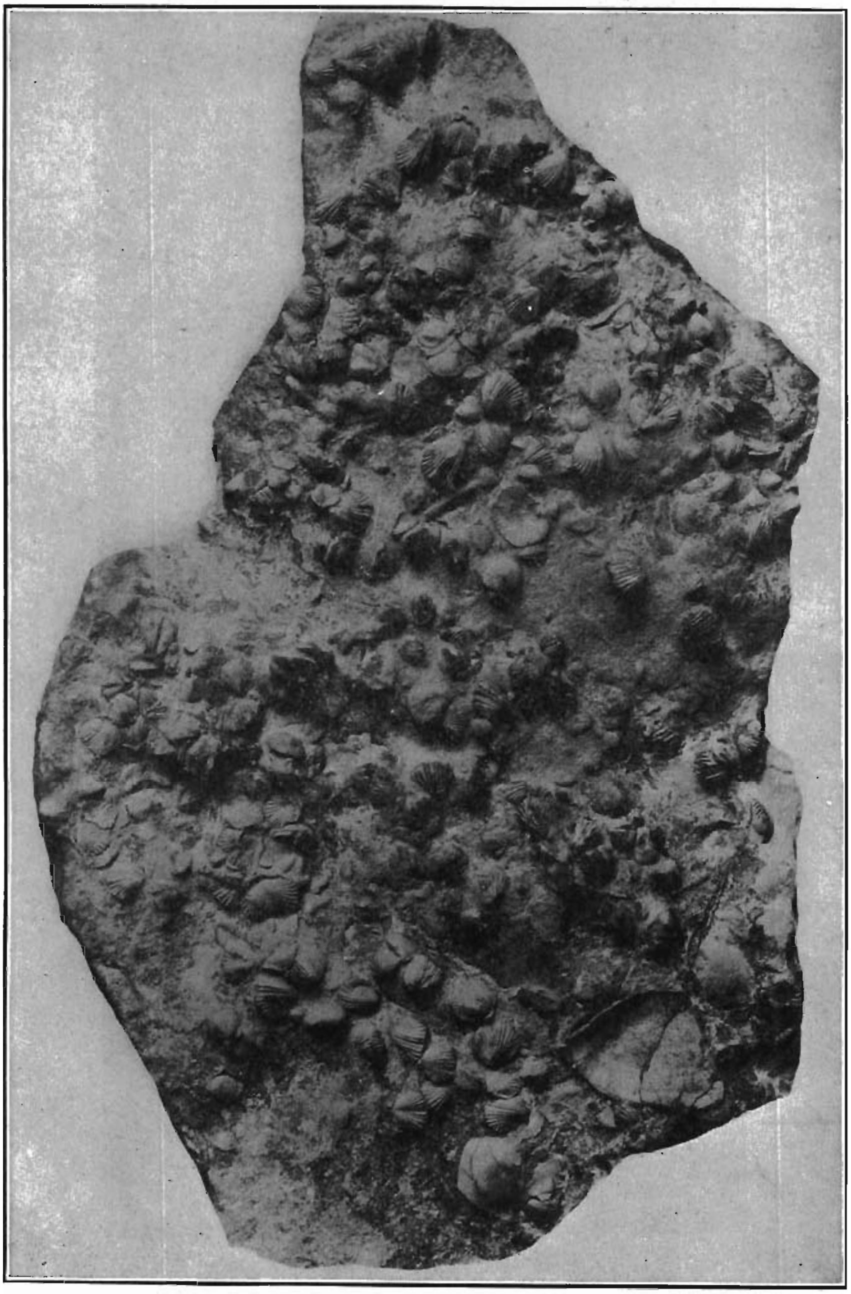
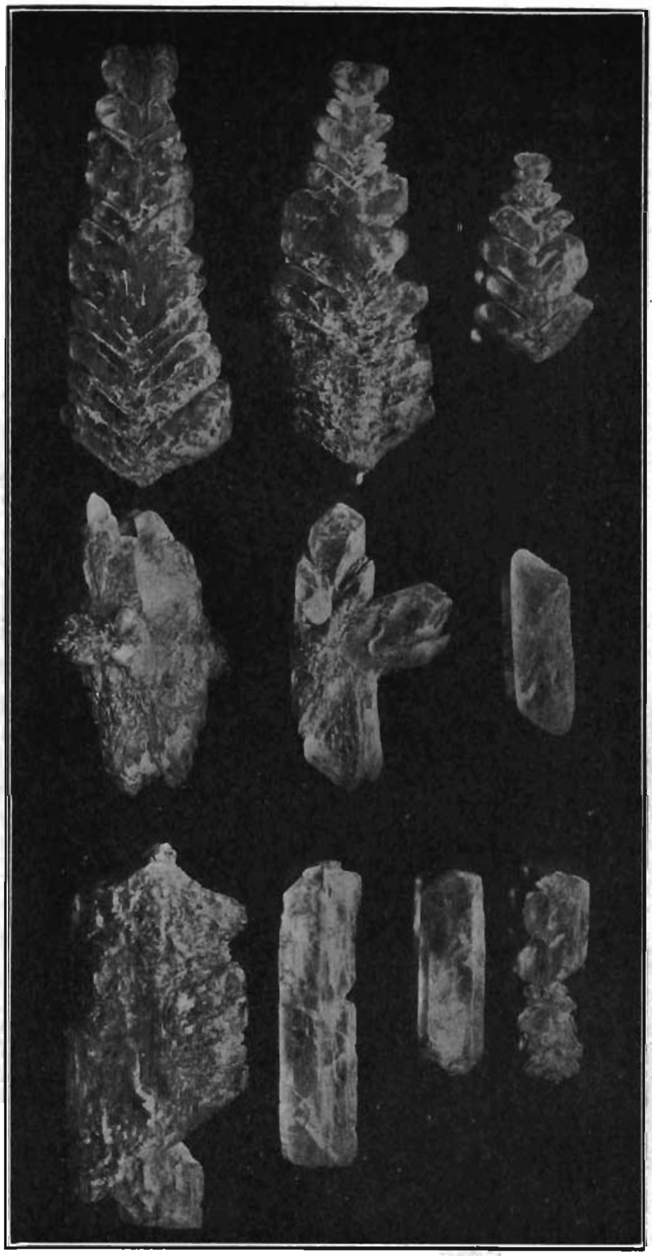


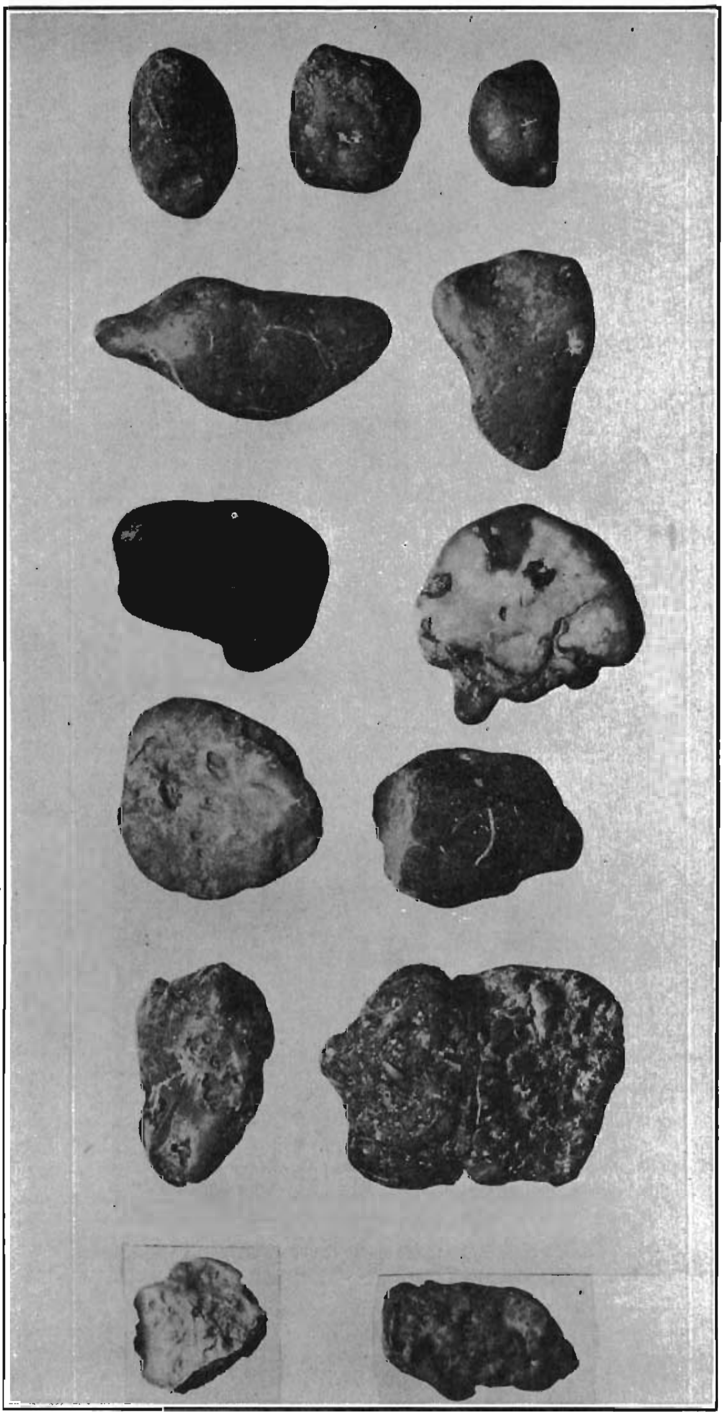
PLATE XII.

An unusual slab from the Cornulites zone of the Southeast Area.

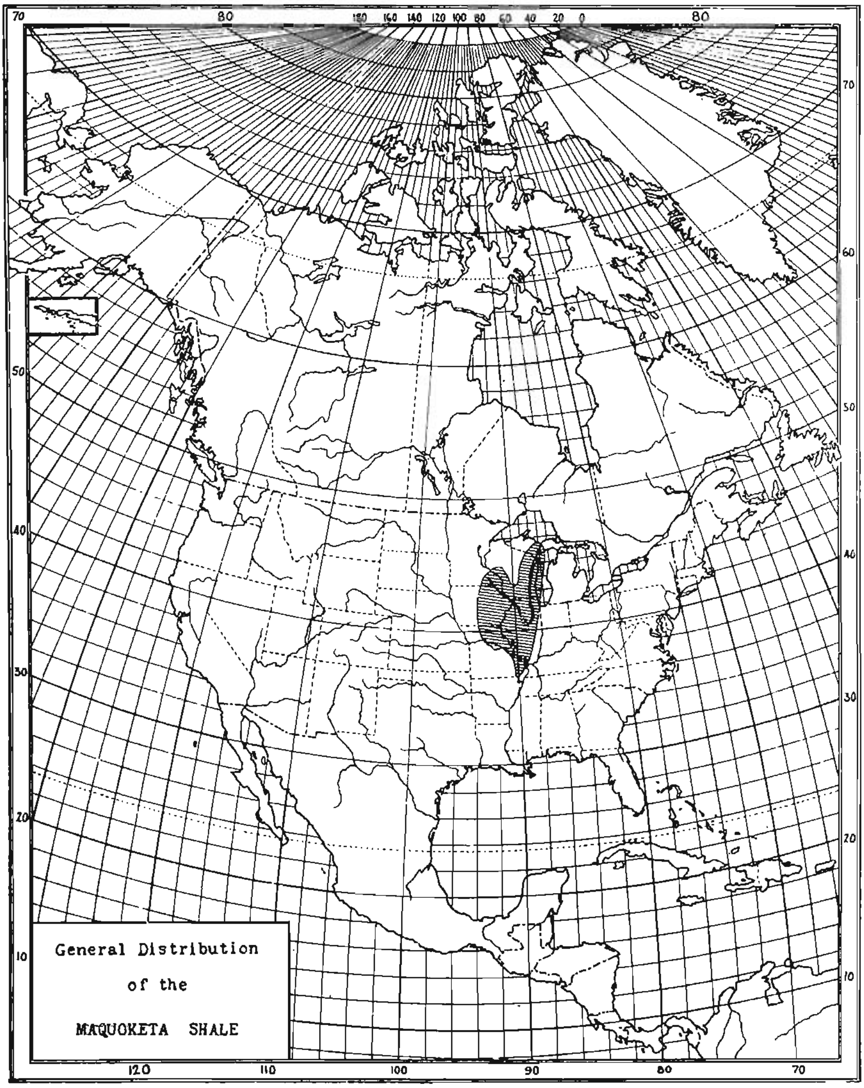




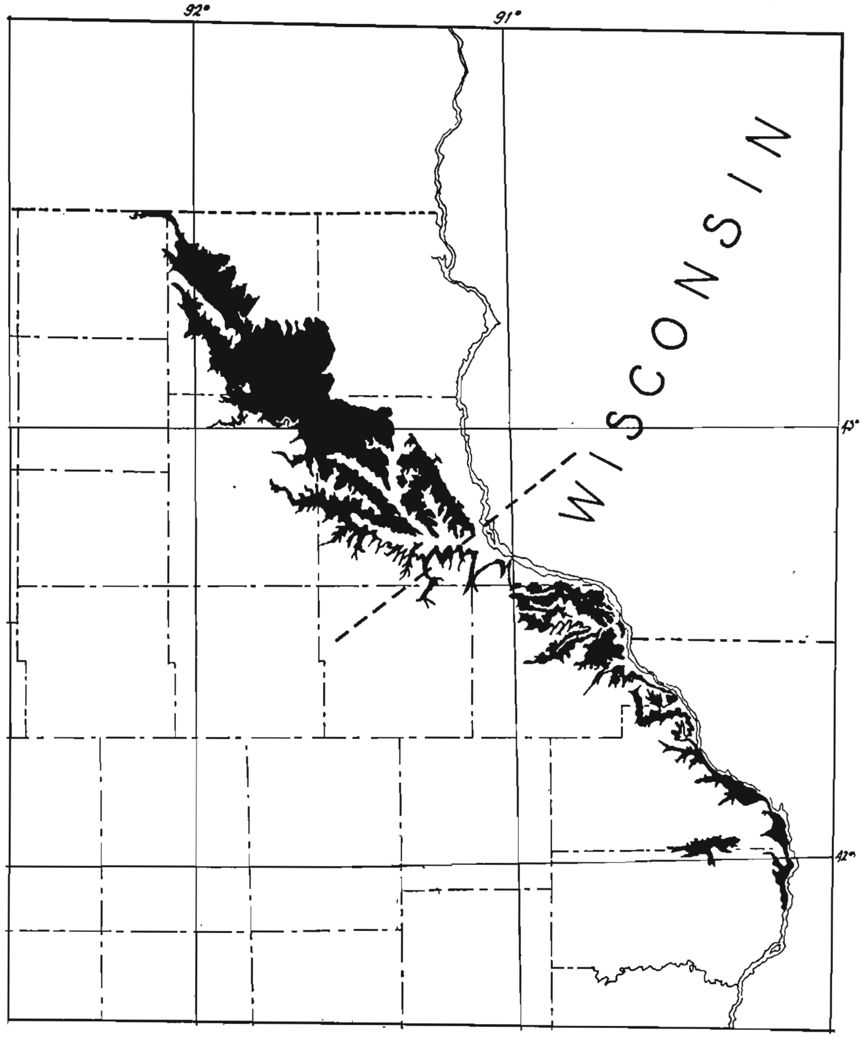
Selenite crystals from the Brainard shale



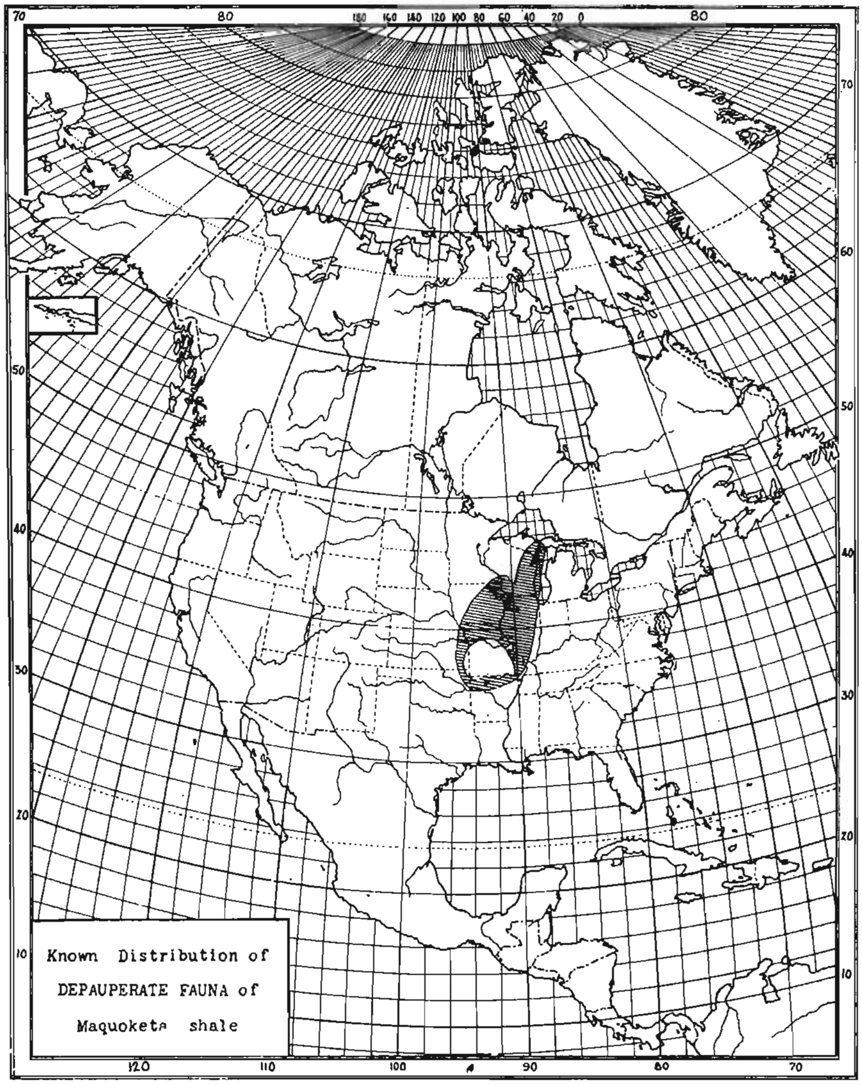
Pebbles from the Depauperate and Cornulites zones of the Maquoketa



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