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Accompanying Papers

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THE ANNUAL REPORT

OF

THE DIRECTOR

TWENTY-EIGHTH AND TWENTY-NINTH ANNUAL
Reports of the State Geologist

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1920.

To Governor William L. Harding and Members of the Geological Board:

GENTLEMEN: I beg leave to transmit to you herewith several papers with the recommendation that they be published as Volume XXIX of the Survey. This Volume will constitute the Twenty-eighth and Twenty-ninth Annual Reports of the Iowa Geological Survey. The titles of the papers submitted and the names of the authors of the papers are as follows:

Mineral Production in Iowa for 1919 and 1920, by James H. Lees.

Petroleum and Natural Gas in Iowa, by Jesse V. Howell.

The Origin and History of Extinct Lake Calvin, by Walter H. Schoewe.

The Missouri Series of the Pennsylvanian in Southwestern Iowa, by John L. Tilton.

New Echinoderms from the Maquoketa Beds of Fayette County, Iowa, by Arthur W. Slocom and August F. Foerste.

Echinoderms of the Iowa Devonian, by Abram O. Thomas.

A brief statement with regard to each of these papers will familiarize you with their content and will enable you to appreciate their value to the people of our State and to persons elsewhere who are interested in the geological features of Iowa.

MINERAL PRODUCTION IN IOWA FOR 1919 AND 1920.

During the years 1919 and 1920 the Survey co-operated as in former years with the United States Geological Survey in the preparation of statistics of mineral production in Iowa.

The value of the output in 1919 amounted at the places of production to $37,882,183, which was $859,826 less than that of the previous year. The decrease was due largely to the smaller output of coal in 1919. On the other hand, in 1920 the mineral production rose to $57,062,317, an increase caused by rises in the output and especially in the values of the chief minerals produced. Coal was the leading product and clay wares, cement, gypsum, and sand and gravel were the other important materials.

In 1919 there was mined 5,624,692 tons of coal which had a value of $17,352,620. The strike of miners lowered the output much below normal as was the case in all the unionized states. In 1920, however, the output increased to 7,774,916 tons with a value of $30,605,847. The average value per ton at the mine rose from $3.08 in 1919 to $3.94 in 1920. Iowa held eleventh place among the coal mining states in 1919. The United States is the largest producer of coal in the world and in 1918 mined 46.2 per cent of the world's total output.

The production of clay wares experienced a healthy growth during both years being considered. The output in 1919 was valued at $8,125,324 and in 1920 at $10,489,232, both of which figures are the largest in the history of the industry in Iowa. The most important product during both years was drain tile, in which this state leads all the states of the Union. The next material in order was fireproofing and the third was common brick. The values of these three in 1920 were $4,760,115, $3,048,776 and $1,146,182 respectively. The unit prices of these products as well as other clay wares show noteworthy increases each year. Iowa is hardly to be ranked as one of the great producers of clay wares, except as to drain tile and hollow building tile (fireproofing), in which she was third in 1920, as she produces annually less than 3 per cent of the national output.

The limestone and lime sold in Iowa in 1919 was valued at $567,356, while that sold in 1920 was worth $840,544. Most of the stone is crushed—over 379,000 tons each year. The use of finely ground limestone in agriculture is increasing as shown by a consumption of over 46,000 tons in 1919 and over 67,000 tons in 1920.

Sand and gravel are important natural resources of the state as is shown by a production of 2,093,471 tons, valued at $1,383,764, in 1919 and of 2,467,644 tons, valued at $1,993,441, in 1920. Nearly half a million tons of gravel and over two hundred thousand tons of sand were used for paving in 1920, while over a million tons of sand and a quarter of a million tons of gravel were used in buildings.

For many years Iowa has been one of the important producers of gypsum and its products—wall plaster, fireproofing tile, blocks, boards, etc., plaster of Paris and other materials. The last report of the Survey dealt with this subject in a most thorough manner. The production of gypsum materials in 1919 and 1920 showed the same upward trend as that of other minerals and rose from a value of $1,976,414 in 1918 to $2,634,444 in 1919 and $4,422,965 in 1920. In both years Iowa ranked next to the leader, New York, in value of output. One of the remarkable features of this industry is the great increase in the output and value of gypsum boards and blocks. In 1917 the production of these materials was 36,504 tons, with an average value per ton of $8.80, but in 1920 the production had risen to 88,212 tons, which sold at an average price of $18.56 per ton. The use of raw gypsum as fertilizer is on the increase as shown by sales of 41,404 tons in 1920, the largest amount shown by any state, as compared with 12,923 tons sold in 1916. It is most gratifying to be able to state to the Board that the published report of our Survey on gypsum which was prepared by Dr. Frank Wilder has been received most enthusiastically by persons in various parts of the world who are interested in gypsum. It will be one of the chief sources of information about gypsum for many years to come.

Only a few years ago Iowa entered the field as a producer of Portland cement, yet today she stands eighth among the states in this regard. The shipments in 1919 and 1920 were valued at $7,798,347 and $8,742,854 respectively. The annual consumption in Iowa is about 3,360,000 barrels, or about 1.40 barrels per capita of her population. This puts her in fourth place in per capita amount. Iowa is also one of the leading states in the production of concrete stone and block. In 1919 she ranked fourth and in 1920 first in this industry. The value of the articles produced was $706,146 in 1919 and $1,397,266 in 1920.

Other materials produced in the state were: mineral waters, valued at $5,703 in 1919 and $3,419 in 1920; potash, of which 89 tons, valued at $20,025, was made in 1919 from sugar beet waste; and natural gas, valued at $185 in 1919 and $290 in 1920. Some ferro-alloys were produced in 1919, although the value is not stated.

PETROLEUM AND NATURAL GAS IN IOWA.

The great demand for petroleum and its products, particularly gasoline and lubricating oils, has led to an intensive search for new supplies and a no less intensive search for buyers of stock in oil companies. In both of these lines of endeavor much of the effort has been honest, however intelligent or uninformed, but much has been fraudulent. Iowa in common with most states of the Union has had her full share of both classes of these two lines of effort and doubtless will have an abundance in time to come. In order to offer the best available information to those who have in view either the undertaking of a search for oil or gas or the investment of money in stocks of oil companies the Survey has had prepared a report on oil and gas in Iowa. The writer of this report, Dr. Jesse V. Howell, has not only been a student of the geology of Iowa for several years but has had five years' experience as petroleum geologist for several oil companies in the Mid-Continent oil fields. Therefore he is in position to write authoritatively on the subject in hand.

The first chapter of the report is devoted to a discussion of the physical conditions attending the formation and accumulation of oil and gas, the surface indications of oil and gas, the geologic conditions and structure of Iowa, including particularly the possibilities of the occurrence of oil and gas in the different geological formations present in the state, and a summary of the evidence regarding the presence of these minerals in Iowa and the areas in which drilling should be especially discouraged.

The writer states that the evidence indicates overwhelmingly that petroleum has been formed from the remains of plants and animals entrapped in marine or brackish water sediments and kept from decaying by the salt in the water. This material was later decomposed by the action of bacteria and through metamorphism of the rocks—that is, changes due to heat and pressure caused by movements of the earth's crust or by weight of overlying strata. Later accumulation of the oil or gas is dependent on the presence of a reservoir of suitable character, in other words of favorable structure and sufficient porosity, and with a cover tight enough to prevent the escape of the liquids or gases. A table gives the geologic horizons in which the oils of the different fields of the United States occur.

One of the interesting points brought out is the relation between the percentage of carbon in the coals of a region and the possibility of the occurrence of oil and gas in that region. It has been shown that where coal contains more than sixty-five per cent of fixed carbon, commercial deposits of oil have not been and probably will not be found. Most of the oil fields of America are in regions where the fixed carbon percentage is between forty-five and fifty-five. Examination of eighteen hundred analyses of Iowa coals shows that they contain from forty-five to sixty per cent carbon. Therefore this factor is not of itself decisive either for or against the presence of oil.

After discussing in detail the structures which are favorable to oil accumulation and the relation of ground water to accumulation Doctor Howell describes the surface indications of oil and gas. One is oil seepages and springs, which while common in some fields are not so in the Mid-Continent fields. Bituminous rocks are more often unfavorable than favorable as they indicate that any oil which was present in the past has escaped through evaporation. Oil shales are rocks containing organic matter which has not yet proceeded far enough in its decomposition to have petroleum. They are not indicators of oil. Coal beds are often considered as evidence of the presence of oil but there is no relationship in origin or in mode of accumulation of the two materials and the presence of one usually indicates the absence of the other. There are many misleading indications, among which are: a scum on quiet waters, which is usually iron oxide rather than oil; a film of oil on drillings or water baled from wells which are being drilled, which comes from the oil used on the machinery; and the similarity of the topography of a region to that of other regions where oil is known to be present, which is absolutely valueless. Even the occurrence of fossils is not an indication of the existence of oil.

The geological formations are discussed in detail and the probabilities of oil being found in such well known horizons as the Platteville (Trenton), Silurian, Devonian, and the Cherokee shales, are considered. The prospect is stated to be distinctly discouraging. The only part of the state for which any hope is held out is the southwestern, including most of the three southern tiers of counties as far east as Winterset, Osceola and Leon. There is no use in drilling, either here or elsewhere, below the upper part of the St. Peter sandstone. The chance of failure, even in southwestern Iowa, is very high.

The second chapter of the report deals with stock promotion and outlines the methods in vogue for selling stock, the conduct of business by the best companies and the character and value of geological reports on oil territory. The writer states that in 1920 the people of Iowa lost nearly $100,000,000 in speculations in oil stocks and that in nearly every case the investors had no chance whatever of even securing the return of the principal. Lured on by the almost universal desire to "get rich quick" people have put their money into schemes which they had not investigated and which were promoted by men of whose ability and integrity and qualifications they knew little or nothing.

Oil companies are organized for producing, transporting, refining and marketing petroleum. Some of the larger companies engage in all these functions, but the smaller ones are able to carry on only one or more and it is usually the first, that of producing oil, which occupies their attention. By far the larger number of fraudulent promotions have been among this class.

The oil business is one of the most hazardous of the legitimate enterprises. Statistics show that only 80 per cent of the oil wells drilled in proven fields are productive. Not over 5 per cent of wild cat wells ever produce. An average well in the Mid-Continent field costs $20,000 and unsuccessful tests costing $200,000 are very numerous. Hence it will be seen that a small company with a limited capital stands a large chance of failure in its attempts to find a productive field. This liability emphasizes the need for securing the best geological advice before locating in a field.

With all these facts to guide the public there is only one safe rule in purchasing oil stocks and that is to invest in going concerns, those which are actually making money. Investment in any other company is speculation pure and simple. It is comparatively easy to distinguish the dishonest promoter as his methods are so sensational and extreme. He enlarges on other fields which have been successful and lists other small companies which have paid large dividends. But he forgets to mention the great number of dry holes which are found in every field and the great number of small companies which have absolutely failed. He usually includes a geological report which is written in glowing terms but is so obscure and complex that the average person can not understand it but is only mystified. An honest geological report is conservative, simply written, prepared by a man of known reputation, and should include a structural map of the region concerned. With such a report in hand and with a knowledge of the assets of the company one is in position to act intelligently regarding the purchase of stock.

This chapter is a splendid compendium of facts and ideas which will be of service to prospective investors, just as the first chapter will be of value in guiding the driller or those whom he may wish to interest in prospecting—"wildcatting" as it is called in oil fields. The report is illustrated by several maps and charts showing the geology and structure of Iowa and also by diagrams showing conditions under which oil and gas may accumulate.

THE ORIGIN AND HISTORY OF EXTINCT LAKE CALVIN

The paper of Doctor Schoewe on the Origin and History of Extinct Lake Calvin will be of special interest to students of Pleistocene geology. Reference to this lake was made first by J. A. Udden in his report on the "Geology of Muscatine County"[1] published in Volume IX of the reports of the Survey. Doctor Schoewe has established beyond a doubt the existence of Lake Calvin. The "fossil" lake is described in detail. Evidence is presented and reasons are given for the belief that Lake Calvin existed for a long time—up to the time of the Iowan ice invasion; for the first time the drainage of the lake is discussed, and the author's view of the origin and history of the lake is presented. The report contains a map showing the extent of Lake Calvin; it covered parts of Muscatine, Cedar, Johnson, Washington, and Louisa counties; its area was about 325 square miles and in places it had a depth of probably 100 feet; the outlet of the lake was at Columbus Junction.

THE MISSOURI SERIES OF THE PENNSYLVANIAN IN SOUTHWESTERN IOWA

The report of Doctor Tilton deals with the sub-divisions of the Missouri series and their locations in southwestern Iowa. Sections are given from outcrops along the rivers and from well records.

The relations of these Missouri strata in the central part of southwestern Iowa have long been misunderstood. This is in part due to the presence of great beds of Dakota sandstone, and of glacial drift that conceal all but scattered outcrops of strata. When Doctor Tilton was detailed to study the geology of Cass county he discovered that the strata were not like the strata at Winterset but were like strata in southwestern Nebraska. Further study brought to light evidence that a fault, or slip in the strata, that had long ago been reported near Missouri river, really extended from the river clear across southwestern Iowa, and how much further no one as yet knows. This fault divides southwestern Iowa into two distinct areas, and becomes the key to the interpretation of relations found.

He then constructed sections from measurements of outcrops obtained along the rivers, and arranged the records of deep wells so as to connect the eastern outcrops extending from Earlham and Winterset south to the state line with records obtained near the southwest corner of the state. This made it evident where the different subdivisions lay beneath the drift. This study of deep well records was further aided by the presence of some outcrops of the rocks themselves. Gradually it became possible to map the general positions of the beds of Missouri strata so largely concealed beneath Dakota sandstone and glacial drift.

The report while thus solving the major features of this complicated problem gives the data on which the conclusions can be tested and points to new problems, particularly in the study of fossils, which are the markers of the different strata. The report also points out the economic bearing of the location of minor folds, indicates the possibility of the presence of coal seams in the northern portion of the area, and by the fault line marks the northern limit of the Nodaway coal.

NEW ECHINODERMS FROM THE MAQUOKETA BEDS OF FAYETTE COUNTY, IOWA

This paper will be of chief value to persons interested in the past life of the State. Part One of the report was prepared by Arthur W. Slocom and Part Two by August F. Foerste.

Part One contains a glossary of crinoid terminology and the descriptions of five species of crinoids, viz: *Archaeocrinus obconicus, Maquoketocrinus ornatus, Porocrinus fayettensis, Dendrocrinus kayi,* and *Ectenocrinus raymondi.* Four of these are referred to existing genera and a new genus, *Maquoketocrinus,* is proposed for the other species. Two of the genera being members of the Rhodocrinidae, that family is discussed at some length; a complete bibliography of the Ordovician species found in America, a table showing their stratigraphic position and an analysis of their generic characters, are given. Several crinoid bases of attachment, presumably belonging to the Heterocrinidae, are figured and described. Three kinds of crinoid columns, some of them having the lower row of plates of the calyx attached, are described but their systematic position is in doubt. Some bead-like columnals, which are abundant in this fauna, are referred to *Atactocrinus* Weller.

Part Two includes a description of one genus, two species, and one variety of crinoids, and one genus and five species of cystoids. The crinoids described are: the genus *Carabocrinus* Billings, the species *Carabocrinus slocomi,* the variety *Carabocrinus slocomi costatus,* and the species *Lichenocrinus minutus;* the cystoids described are: the genus *Pleurocystites* Billings, and the species *P. beckeri, P. slocomi, P. clermontensis, P.* sp., *P. multistriatus.* Certain species of *Carabocrinus* occurring in North America are compared with the European species *C. esthonus* Jaekel, suggesting the migration of the species from North America to northern Europe. The data presented indicate that *Lichenocrinus* may possibly occur in northern faunas. The genus *Pleurocystites* Billings is compared with other cystoids of the family Cheirocrinidae. The species *P. multistriatus* is compared with *P. angularis* and *P. anticostiensis.*

ECHINODERMS OF THE IOWA DEVONIAN.

This paper by Dr. A. O. Thomas is a contribution to the paleontology of the rocks of the Iowa Devonian system. These rocks are notable for the great variety and abundance of their fossil content. The remarkable fish remains described by Doctor Eastman in Volume XVIII of the Survey Reports were found in these rocks. Other groups of the Devonian fossils are being studied and illustrated by Doctor Thomas.

Echinoderms include such forms as the crinoids or sea-lilies, the blastoids, the cystoids, the echinoids or sea urchins, the starfishes, and some others. Each of the above named groups except the starfishes had known representatives in the Devonian of Iowa. While crinoids are not as abundant in the Devonian as in the overlying Mississippian rocks and while there are no famous localities such as at Burlington, Keokuk, or Le Grand, yet the Devonian rocks in places are filled with the comminuted parts of crinoids and a number of highly interesting forms have been found complete enough for study. Blastoids and cystoids belonging to rare and highly specialized genera occur and a number of new sea urchins add much interest to the total assemblage.

In all forty-three species and two varieties are described and illustrated. Twenty-four of these species and the two varieties are new. Two of the genera are new and seven more of the twenty-two genera are reported from the Iowa Devonian for the first time. The other thirteen genera and nineteen species have been described in widely scattered literature. References to these have been brought together and some descriptions by other authors have been quoted verbatim, comments have been added, localities have been fully listed, and bits of history have been given of some of the specimens. Other details touching upon the work of the pioneer geologists, Owen, Hall, Wachsmuth, Barris, Calvin, and others have been interspersed.

A study of the distribution of the Iowa Devonian Echinoderms outside the state shows that only seven of the forty-three species are extralimital but of the twenty-two genera only three are wholly limited to the Devonian of this state. A table brings out the geographic and stratigraphic range of the genera. Some of them are widely distributed in North America and a few are to be found in nearly contemporaneous beds in Europe. The table also shows that the genera are dominantly late Devonian and early Mississippian rather than Silurian and early Devonian, a fact which corroborates the placing of all our Devonian in the upper series of that system as the author has done. A synoptic table of the Iowa Devonian rocks is given. As intimated above a number of rare and interesting genera heretofore remote from Iowa have been recognized for the first time in our Devonian. Such are *Arthracantha,* previously known from New York and Ontario, *Dactylocrinus,* a rare but world wide genus, and *Xenocidaris,* a form only meagerly known from the Devonian of Germany.

The genera *Melocrinus* and *Megistocrinus* are the commonest in our area and their dissociated calyces, arms, and stems make up the greater part of the crinoidal limestone of Devonian age. *Melocrinus is* represented by six species and *Megistocrinus* by eight. *Hexacrinus* is a common genus in the Devonian of Europe. It is rare in America. This paper shows that only four species of *Hexacrinus* have been found in North America, three of these are from the Iowa Devonian, two of them being new. The most striking forms described by the author belong to certain genera of sea urchins found in the Lime Creek beds. Remains of these animals are very rare in early Paleozoic rocks but in the Mississippian system they are relatively abundant. Four species and one variety belonging to three different genera are described in the paper. This practically doubles the number of known echinoids below the Mississippian in North America. One of the new genera, *Nortonechinus,* is remarkable for its large number of interambulacral rows of plates, for the great amount of overlapping of these plates one upon the other, and for the peculiar spines whose outer ends are flattened and polygonal instead of being pointed. These spine apices were in contact and formed a sort of coat-of-mail outside the covering of moveable plates. Ambulacral plates and parts of the lantern are also described. *Devonocidaris,* another new genus, has long slender spines and thin delicate plates. *Xenocidaris,* of which only a few spines have been known from Europe, is represented by abundant spines and some other parts. These sea urchins have European affinities, a fact which some of the crinoids, notably *Dactylocrinus* and *Hexacrinus,* also emphasize.

An analysis of the fauna shows four species of cystoids, four blastoids, nineteen camerate crinoids, six flexible crinoids, five inadunate crinoids, and five echinoids. There is also one new variety of crinoids and one of the echinoids. A large parasitic snail which lived on one of the crinoids has been briefly described.

The fossils have been illustrated in a series of twenty plates on which are five hundred separate illustrations. There are also twenty text figures most of which are devoted to the elucidation of parts of the various species and to the plans of certain crinoid calyces.

OTHER PAPERS SOON TO BE PUBLISHED

Several other papers dealing with important phases of the geology of Iowa will soon be ready for publication. Among these may be mentioned reports by Dr. S. L. Galpin on the Clays of the State; by Dr. F. M. Van Tuyl on the Mississippian System of Iowa; by Dr. James H. Lees on the Geology of Crawford County; and by Dr. A. J. Williams on the Glacial History of Northeastern Iowa.

ADDITIONAL INVESTIGATIONS OF THE SURVEY

The Director of the Survey has been interested for several years in some of the problems involved in the interpretation of the glacial history of our State. Recently field studies have been carried forward in western Iowa. The chief purpose of the investigation here has been to determine whether or not a re-study of the tills, gravels and related deposits of the area would permit, in the light of our most recent knowledge of the Pleistocene of southern, southwestern and northwestern Iowa, a more satisfactory interpretation of the relationships and origins of these glacial materials than was possible when previous studies were made. Considerable additional field work will be necessary before final conclusions can be reached, but thus far the evidence warrants the following tentative statements:

1. The two oldest known tills, the Nebraskan till and the Kansan till, separated in many places by Nebraskan gumbotil of Aftonian age and in other places by peat, lignite and soil zones of Aftonian age, have been traced as far west as the western parts of Crawford and Shelby counties, a distance of less than 25 miles from the Missouri river, the western boundary of Iowa. Moreover, in the southeastern part of the town of Council Bluffs, in Pottawattamie county, there is a distinctive zone of leached Nebraskan till separating unleached Nebraskan till below this zone from unleached, oxidized Kansan till above the zone. The evidence in hand seems to indicate that both these two old tills extend to the Missouri river and probably also beyond into the State of Nebraska. If it were not for the thick deposits of loess overlying the tills in this

region no doubt many additional good sections of these two tills could be seen.

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

3. The sands and gravels of western Iowa which have been described by Shimek and Calvin as being Aftonian interglacial gravels separating the Nebraskan till from the Kansan till and not related in origin to deposits made either during the closing stages of the Nebraskan glacial epoch or during the Kansan glacial epoch are thought by the writer to represent not a distinctive stratigraphic horizon separating the Nebraskan till from the Kansan till. But instead they are interpreted as being lenses and irregularly shaped masses of gravels and sands within a single till, or, if in two tills, the Nebraskan and the Kansan, it is not possible to use the gravels and sands as evidence for differentiating these two tills. The gravels and sands are unleached and appear to be contemporaneous in age with the tills with which they are associated. This view is in accord with the author's interpretation, recently published, of the relationships to till of the well known gravels near Afton Junction and Thayer in Union county.

4. Many mammalian fossils have been found in the sands and gravels associated with the tills of western Iowa. Calvin and Shimek believed that these remains were of animals which were living during the time of deposition of the gravels, which they interpreted as Aftonian and interglacial. But

if the sands and gravels are lenses and irregularly shaped pockets related in age to the till with which they are associated, then a somewhat different interpretation of the age of the mammals becomes necessary. At the present time it is impossible to state whether the gravels in which the mammalian remains have been found are associated with Nebraskan till or with Kansan till since, as stated previously, it has not been possible thus far to differentiate Nebraskan till from Kansan till except where the relationships of the till to gumbotil the age of which is known have been established. If the gravels in which the mammalian remains have been found should prove to be lenses and pockets in Nebraskan till then the evidence would suggest that the animals are Nebraskan in age. It would be reasonable to assume that the animals were living in front of the advancing Nebraskan ice sheet, out from which sands and gravels were being carried. Remains of mammals became imbedded in the sands and gravels, which themselves later became incorporated in the onward moving Nebraskan till. If, on the other hand, the sands and gravels containing the mammalian remains should prove to be lenses and pockets in Kansan till then the suggested interpretation would be that the mammals were living on the Aftonian surface during the advance of the Kansan ice sheet out from which sands and gravels were being carried. After remains of mammals became imbedded in these sands and gravels the Kansan ice sheet advanced and incorporated in Kansan till these masses of sands and gravels in which the remains are found.

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

5. The name Loveland formation was given by Shimek to a deposit in western Iowa which is a "heavy, compact, red-

dish (especially on exposure to the air) or sometimes yellowish silt, which when dry is hard, with a tendency to break into blocks like a joint clay, and when wet becomes very tough and sticky and hence is sometimes called a gumbo.'' The type section of this formation is at Loveland, Harrison county. By early workers this formation was thought to be related to the widespread buff loess of the region, but Shimek believes that it is a fluvio-glacial deposit ''formed during the melting of the Kansan ice.'' In many places it is calcareous and contains calcium carbonate concretions, many of which are from 3 to 6 inches in diameter; a few were seen with greatest diameter more than 12 inches. The Loveland does not show the laminations of water-laid clay, but in places sands and silts of distinct aqueous origin are interstratified with the Loveland clay; and in a few places volcanic ash is interbedded with the formation. Moreover, it has the vertical cleavage of loess and stands with similar vertical faces. Although in places fossil shells are present in the Loveland they are extremely rare in comparison with the numbers of shells which are in the buff loess. The writer believes that the Loveland is not a fluvio-glacial deposit but a loess distinctly older than the widespread buff loess which overlies the Loveland and which is thought to be chiefly of Peorian age; the Loveland is younger than the Kansan glacial epoch, since it lies upon the maturely eroded surface of Kansan till.

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

The Assistant State Geologist, Dr. James H. Lees, is studying the geology of several of the counties of the State. Moreover, he is rendering valuable service in editing reports of the Survey. He is by correspondence and by personal visits furnishing information to persons interested in the development of one or more phases of the geology of the State.

The Survey is co-operating with the United States Geological Survey in the work of stream gaging and discharge measurements of the State, in the collecting of mineral statistics, and in the preparation of topographic maps. In connection with the stream gaging the Survey co-operates also with the Iowa State Highway Commission and the Mississippi River Power Company.

Dr. W. H. Norton continues to furnish to the municipalities of the State useful information with regard to the underground waters of Iowa.

WORK OF THE SURVEY OFFICE

The work of the office has been in charge of Dr. James H. Lees, Assistant State Geologist, and Miss Nellie E. Newman, Secretary. Among the many kinds of service being rendered by officers of the Survey, permit me to refer again to those which have been emphasized frequently in reports to the Board:

1. Replying to scores of letters in which information is asked with reference to the geology and mineral resources of the State. In much of this correspondence questions are asked with reference to local geology.

2. Furnishing information in regard to state reports and other publications dealing with the geology and mineral resources of the various sections of the state.

3. Itemizing and reporting on numerous specimens of minerals and fossils which are submitted by the citizens of the state. Advice is given as to whether or not the minerals are of value or are likely to be found in sufficient quantity to be of commercial importance.

4. Giving advice with regard to reliable firms where analyses and other tests may be made to establish the commercial value of any mineral deposit.

5. Trying to prevent an unfounded rumor from gaining ac-

ceptance in the public mind with regard to the reputed discovery of gold, oil, or other product before it leads to large losses and unnecessary excitement.

6. Giving the geological facts to city officials, railway companies, and private citizens with regard to water supplies, availability of road materials, etc.

7. Informing citizens regarding the advisability or inadvisability of investing time and money in the development of particular deposits of mineral within the state.

Respectfully submitted,

GEORGE F. KAY,

State Geologist

MINERAL PRODUCTION IN IOWA IN 1919 AND 1920

BY

JAMES H. LEES

MINERAL PRODUCTION IN IOWA IN 1919 AND 1920[1]

Product	Unit	Quantity	Value	
	1918			
Cement	Barrels	3,188,669	$ 5,423,926	
Clay products		————	5,315,143	
Clay, raw	short tons	5,416	3,705	(a)
Coal	short tons	8,192,195	24,703,237	
Gypsum	short tons	327,927	1,946,414	
Mineral waters	gallons sold	87,703	3,937	
Natural Gas	M cubic feet	1,758	245	
Sand and gravel	short tons	2,004,444	904,307	
Stone and lime		————	444,800	
Miscellaneous (c)		————	1,120,418	
	Total value		$38,742,009	
	1919			
Cement	Barrels	4,569,110	$ 7,798,347	
Clay products		————	8,125,324	(a)
Coal	short tons	5,624,692	17,352,620	
Gypsum	short tons	421,279	2,634,444	
Mineral waters	gallons sold	39,661	5,703	
Natural gas	M cubic feet	740	200	
Potash	short tons	89	20,025	
Sand and gravel	short tons	2,093,471	1,383,764	
Stone and lime	short tons	519,030	567,356	
Miscellaneous (b)		————	474,900	
	Total value, eliminating duplicates		$37,882,183	
	1920			
Cement	Barrels	4,421,783	$ 8,742,854	
Clay products		————	10,489,232	(a)
Coal	short tons	7,774,916	30,605,847	
Gypsum	short tons	571,895	4,422,965	
Mineral waters	gallons sold	38,877	3,419	
Natural gas	M cubic feet	827	290	
Sand and gravel	short tons	2,467,644	1,993,441	
Stone and lime	short tons	620,565	840,544	
	Total value, eliminating duplicates		$57,062,317	

(a) Includes pottery and raw clay sold. Value of raw clay not included in total value for state.
(b) Not included in total value for state. Includes ferro-alloys and raw clay sold.
(c) Not included in total value for state.

The value of the minerals produced in Iowa in 1919 was $37,-882,183, a decrease of $859,826 from the production of 1918. This decrease simply reflects the reaction from wartime production which had begun in 1918, and also the unsettled condition of industry in general. Specifically the decrease is due

[1] As in previous years the mineral statistics have been compiled by the Iowa Geological Survey and the United States Geological Survey in cooperation.

largely to the smaller output of coal, as the value of the other major materials produced was somewhat larger in 1919. On the other hand the value of the output for 1920, $57,062,317, was nearly twenty million dollars more than that of the preceding year. An inspection of the tables given above shows that this large increase was caused chiefly by the great rise in the value of the coal produced, as well as in its larger amount, and also by the increased output and larger values of the other minerals. This again reflects the change which had come over business, for although there was still much unrest, prices were showing an upward trend.

Coal still held the chief place among Iowa mineral products and its comparative value rose from twice that of its nearest competitor, clay products, in 1919 to nearly three times in 1920. Clay products, cement, gypsum and sand and gravel held the rank here indicated during both years and with coal made up much the greater part of the production.

It has been impossible to secure detailed statistics for the output of some of the minerals during 1919, hence itemized tables giving the production during this year can not be presented. Table I shows the production in the various counties during 1920, so far as these may be revealed. It shows that eighty counties shared in the mineral production of the state, and that of these twenty produced coal, fifty produced clay wares, forty-two produced sand and gravel and eighteen produced stone and lime. In addition twelve counties produced miscellaneous materials including cement, which came from three counties, gypsum, which came from two, mineral waters, which came from five, and natural gas, which came from two counties.

TABLE I.

TABLE OF MINERAL PRODUCTION IN IOWA IN 1920.

County	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[a]	Total Value
Adair	1				*		*
Adams	4	$ 38,734					$ 38,734
Allamakee	3		*	*			108,557
Appanoose	64	6,798,711	*			*	6,899,267
Audubon	1		*				*
Benton	4		$ 79,846				79,846
Black Hawk	6			*	$ 66,484		*
Boone	6	1,276,005	*		*		1,551,328
Bremer	2				*		*
Buena Vista	3		*		*		*
Butler	2				*		*
Cass	1		*				*
Cedar	1		*				*
Cerro Gordo	12		2,818,423	*	*	*	9,353,883
Cherokee	3				92,058		92,058
Clay	1				*		*
Clayton	2			*	*		*
Clinton	6		*	*	19,300		*
Dallas	9	1,676,646	1,082,955				2,759,601
Des Moines	4		*	*	*		68,349
Dickinson	1					*	*
Dubuque	11		*	94,521	*	*	146,660
Emmet	3				*	*	8,156
Fayette	4				41,275		41,275
Floyd	1		*				*
Franklin	5		*		3,165		*
Greene	2	*					*
Guthrie	3	*				*	1,310
Hancock	1		*				*
Hardin	3		*	*	*		157,950
Harrison	1				*		*
Henry	3		*	*			*
Howard	2		*	*			*
Humboldt	1				*		*
Ida	1				*		*
Iowa	2		*				*
Jackson	6		*	*	16,035		124,443
Jasper	5	*	*			*	84,353
Jefferson	3	*	*				*
Johnson	5		*		18,210		*
Jones	6		*	87,819	*		112,268
Keokuk	6	*	452,541				*
Kossuth	1		*				*
Lee	4		*	63,595			*
Linn	6		*	*	63,199		*
Louisa	3		*			*	3,240
Lucas	3	1,232,883					1,232,883
Lyon	2				*		*
Madison	2		*	*			*
Mahaska	14	220,157			*		*
Marion	17	2.789.771	284.527		*		*

TABLE OF MINERAL PRODUCTION IN IOWA IN 1920.

County	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products[a]	Total Value
Marshall	1				*		*
Mills	1		*				*
Mitchell	1			*			*
Monroe	11	9,769,187					9,769,187
Muscatine	6		*		128,908		*
O'Brien	4		*		7,867		7,867
Osceola	3				6,707		6,707
Page	3	*	*				*
Palo Alto	1				*		*
Plymouth	3				18,419		18,419
Pocahontas	1			*		*	*
Polk	38	4,689,550	1,200,330		469,155	*	*
Poweshiek	4		53,548				53,548
Sac	3		*		*		*
Scott	8		*	291,850	*		411,879
Sioux	5				77,940		77,940
Story	2		*				*
Tama	4		81,257				81,257
Taylor	1	*					*
Union	1		*				*
Van Buren	4	37,236					37,236
Wapello	23	563,574	202,133		79,584		845,291
Warren	2	*	*				*
Washington	4		111,190				111,190
Wayne	2	*					*
Webster	17		1,144,062		40,999	*	*
Winneshiek	3		*		*		*
Woodbury	5		531,383		*	*	*
Wright	3		*		*		*
Counties with less than three producers in any one industry		1,701,393	2,397,762	537,785	884,136	13,169,528	18,690,604
Totals	426	$30,793,847	$10,489,232	$840,544	$1,993,441	$13,169,528	$57,062,317

*Included in counties with less than three producers.
[a]Includes: Cement, $8,742,854; gypsum, $4,422,965; mineral waters, $3,419; natural gas, $290.

COAL MINING.

As was stated above detailed statistics for 1919 are not available, but the summary reports show the following facts:

	Tons	Value
Loaded at mines for shipment	4,849,636	$14,672,888
Sold to local trade or used by employees	610,937	2,294,561
Used at mine for power and heat	164,119	385,171
Total production in 1919	5,624,692	$17,352,620
Average number of days mines were operated	176	
Average number of men employed—		
Underground	10,873	
Surface	1,493	
	12,366	

These figures, when compared with those for 1918, which show a tonnage of 8,192,195 valued at $24,703,237, show markedly the effect of slack demand in the first part of the year and the strike during November. On the other hand, the figures for 1920 show a large increase in the output and a sharp rise in prices.

Table II shows the figures for this year.

TABLE II.

COAL PRODUCTION IN 1920 BY COUNTIES.

County	No. Producers	Loaded at Mines for Shipment		Sold to Local Trade and used by Employees		Used at Mines for Steam and Heat		Total Quantity		Number of Employees			Av. No. of days worked
		Short Tons	Value	Short Tons	Value	Short Tons	Value	Short tons	Value	Under-ground	Surface	Total	
Adams	4	....	....	8,419	$ 38,734	....	....	8,419	$ 38,734	34	6	40	168
Appanoose	62	1,411,232	$ 6,385,927	75,921	340,910	24,446	$ 71,874	1,511,599	6,798,711	2,840	330	3,170	242
Boone	3	254,913	935,329	60,404	322,594	7,200	18,082	322,517	1,276,005	540	51	591	239
Dallas	4	428,629	1,610,909	9,864	47,506	6,177	18,231	444,670	1,676,646	589	60	649	272
Greene and Guthrie	3	....	....	8,022	40,100	....	....	8,022	40,100	19	3	22	190
Jasper, Jefferson, Keokuk	5	180,961	727,466	31,600	151,545	10,025	31,784	231,586	910,795	316	47	363	216
Lucas	3	370,150	1,149,222	12,592	37,840	14,940	45,821	397,682	1,232,883	581	48	629	237
Mahaska	13	Included in "Sold to Local Trade"		64,430	220,157	Incl. in "Sold to Local Trade"		64,430	220,157	80	16	96	223
Marion	12	756,483	2,617,307	30,630	112,676	18,610	59,788	805,723	2,789,771	903	92	995	267
Monroe	11	2,409,358	9,468,153	39,568	157,387	54,350	143,647	2,503,276	9,769,187	2,806	258	3,064	259
Page and Taylor	3	4,745	24,000	18,161	91,100	....	....	22,906	115,100	53	5	58	251
Polk	17	864,452	3,306,742	292,538	1,305,624	26,832	77,184	1,183,822	4,689,550	1,568	157	1,725	255
Van Buren	4	Included in "Sold to Local Trade"		7,538	37,236	....	....	8,845	37,236	14	5	19	274
Wapello	16	Included in "Sold to Local Trade"		141,823	558,205	1,970	5,369	143,793	563,574	221	38	259	221
Warren and Wayne	4	93,163	345,864	16,531	74,302	7,932	27,234	117,626	447,398	193	32	225	244
Small Mines		30,000	150,000	9,000	38,000			39,000	188,000				
		6,929,214	$27,128,512	711,187	$3,162,757	173,515	$502,578	7,813,916	$30,793,847	10,757	1,148	11,905	250

The tables show an increase in the average value at the mine from $3.08 per ton in 1919 to $3.94 per ton in 1920, an increase which may be attributed in part to improving business conditions and in part to increased competitive buying, as the stocks had been much reduced during the later part of 1919.

The leading coal producing states of the Union were ranked in 1919 as follows:

	Tons	Value
Pennsylvania (bituminous)	150,758,154	$ 365,430,504
West Virginia	79,036,553	196,551,015
Illinois	60,862,608	140,075,969
Ohio	35,876,682	79,496,301
Kentucky	30,036,061	73,891,049
Indiana	20,912,288	46,345,750
Alabama	15,536,721	45,937,681
Colorado	10,323,420	28,745,534
Virginia	9,326,830	23,774,941
Wyoming	7,219,738	18,751,024
Iowa	5,624,692	17,352,620
Kansas	5,224,724	15,917,053
Total bituminous	465,860,058	1,160,616,013
Pennsylvania anthracite	88,092,201	364,926,950
Total for U. S.	553,952,259	$1,525,542,963

A comparison of these figures with those for 1910 shows that in the earlier year Iowa produced 7,928,120 tons, valued at $13,903,913, an average price of $1.75 per ton. In that year Iowa ranked ninth in tonnage and value of output. In 1919 the tonnage was 2,303,428 less than a decade previous, but the value had increased $3,448,707, a rise in average value of $1.33 per ton. During the later year Iowa ranked eleventh in tonnage and value, having been passed by Virginia and Wyoming.

A list of the chief producers of coal in 1918, the last year for which statistics are available, includes the following. Figures are short tons and are tentative.

United States	678,211,904
Great Britain	255,040,328
Germany	273,930,000
France	30,864,000
Belgium	15,229,000
Japan	30,600,000
Canada	14,979,213
New South Wales	10,160,000
Union of South Africa	11,937,682
Holland	5,277,813

Queensland	1,101,176
Dutch East Indies	1,000,000
Approximate total for the world	1,468,000,000
Per cent produced by United States	46.2

CLAY PRODUCTS.

Clay products increased largely in value in 1919 over the output for 1918, the increase being from $5,318,848 to $8,125,324. This increase was accounted for by the removal of war restrictions and the partial return to normal industrial and business conditions. In 1920 the value of the product rose still higher—to $10,489,232.

The following summary will give an idea of the progress of the industry.

	1918		1919	
	Quantity	Value	Quantity	Value
Common brick	67,292 M	$ 749,325	66,632 M	$ 941,489
Vitrified brick	6,793 M	116,522	8,673 M	179,969
Face brick	11,383 M	188,041	20,603 M	449,491
Drain tile		2,256,200	341,587 tons	3,127,378
Sewer pipe		398,848	43,698 tons	902,008
Fireproofing	238,789 tons	1,550,076	249,335 tons	2,475,291
Other products		32,206		31,975
Pottery and clay		5,454		17,723
		$5,318,848		$8,125,324

	1920	
	Quantity	Value
Common brick	60,270 M	$ 1,146,182
Vitrified brick	6,116 M	176,430
Face brick	13,678 M	346,164
Drain tile	453,122 tons	4,760,115
Sewer pipe	41,634 tons	918,669
Fireproofing	293,081 tons	3,048,776
Other products		43,621
Pottery and clay		49,275
		$10,489,232

These summaries reveal the upward trend in prices during the three years represented and this trend may be shown also by the following table of average prices received.

	1918		1919		1920	
	Iowa	United States	Iowa	United States	Iowa	United States
Common brick	$11.14	$10.90	$14.12	$13.38	$18.95	$16.95
Vitrified brick	17.15	17.74	20.75	23.74	28.85	27.06
Face brick	16.52	17.10	21.82	20.27	25.31	24.71
Drain tile			9.32	8.82	10.51	10.51
Sewer pipe			20.64	14.50	22.07	21.34
Fireproofing	6.49	6.67	8.40	7.71	10.40	10.62

Iowa's rank among the states of the Union is shown by the following table:

TEN LEADING STATES IN VALUE OF CLAY PRODUCTS.

State	1919 Rank	1919 No. of firms reporting	1919 Value, not including raw clay sold	1919 Percentage of total	1920 Rank	1920 No. of firms reporting	1920 Value, not including raw clay sold	1920 Percentage of total	Increase in 1920; per cent.
Ohio	1	416	$ 63,787,319	23.2	1	386	$ 82,061,960	21.9	28.6
Pennsylvania	2	336	39,270,613	14.3	2	307	50,983,988	13.6	29.8
New Jersey	3	126	26,545,959	9.6	3	137	40,021,028	10.7	50.8
Illinois	4	142	17,408,022	6.3	4	156	26,138,419	7.0	50.2
New York	5	120	14,468,586	5.2	5	142	19,113,684	5.1	32.1
West Virginia	6	59	13,097,598	4.8	7	55	17,167,843	4.6	31.1
Indiana	7	163	11,634,097	4.2	8	149	15,494,795	4.1	33.2
Missouri	8	65	10,997,949	4.0	6	73	17,474,542	4.7	58.9
Iowa	9	115	8,125,324a	2.9	10	109	10,489,232a	2.8	28.8
California	10	66	5,834,648	2.1	9	65	10,946,423	2.9	87.6
Total U. S.		2,776	$275,346,378			2,716	$373,670,102		35.7

a Includes raw clay sold.

In brick and tile products Iowa ranked eighth in both 1919 and 1920. In common brick she ranked twenty-first in 1919 and twentieth in 1920. In hollow building tile she ranked second in 1919, being exceeded by Ohio alone, and third in 1920, as New Jersey passed her by about half a million dollars. In drain tile Iowa was, as usual, the leader, her nearest competitor, Ohio, being well over a million dollars behind in 1919, and over three million in 1920. In sewer pipe Iowa ranked sixth in 1919, but dropped to eighth in 1920, as her production remained almost stationary while that of the other leading states increased largely.

Table III shows the output of clay wares by the different counties in the two years here considered.

TABLE III

VALUE OF CLAY PRODUCTS IN 1919.

County	No. of Producers	Common Brick	Drain Tile	Hollow Building Tile	Other Products[c]	Total Value
Allamakee	1	*	*	*	....	*
Appanoose	1	*	....	....	....	*
Audubon	2	*	*	*	....	*
Benton	3	*[a]	20,822	12,002	....	32,824
Boone	2	*	*	*	*	*
Buena Vista	2	....	*	....	....	*
Cass	1	*	*	*	....	*
Cedar	1	*	*	*	....	*
Cerro Gordo	6	*[a]	934,640	590,165	....	1,524,775
Clinton	1	*	*	....	....	*
Dallas	5	....	201,692	414,310	....	616,002
Des Moines	1	*	*	*	....	*
Dubuque	2	*	....	....	....	*
Fayette	1	*	....	*	*	*
Floyd	1	*	*	*	....	*
Franklin	2	*	*	*	....	*
Grundy	1	*	....	....	*	*
Guthrie	1	....	*	*	....	*
Hamilton	1	....	*	....	*	*
Hancock	1	....	*	....	....	*
Hardin	1	....	*	....	....	*
Henry	2	*	*	*	....	*
Howard	1	*	*	*	....	*
Humboldt	1	....	*	....	....	*
Iowa	2	*	*	*	....	*
Jackson	1	....	....	*	....	*
Jasper	2	*	*	*	....	*
Jefferson	3	*	30,673	*	....	38,778
Johnson	1	*	*	....	....	*
Jones	2	*	*	*	....	*
Keokuk	5	*	215,822	*	*	328,970
Kossuth	1	....	*	....	....	*
Lee	1	*	....	....	....	*
Linn	1	....	*	....	....	*
Louisa	1	....	*	*	....	*
Madison	1	....	*	*	....	*
Mahaska	1	*	*	*	*	*
Marion	4	4,326	54,707	134,816	....	193,849
Marshall	1	*	*	*	....	*
Mills	1	*	....	....	....	*
Muscatine	2	*	....	....	....	*
Page	1	*	*	*	....	*
Polk	8	*[a]	274,042[b]	265,503	462,848	1,002,393
Pottawattamie	1	*	....	....	....	*
Poweshiek	4	*[a]	27,403	8,389	....	35,792
Sac	1	*	*	*	....	*
Scott	2	*	*	*	*	*
Story	2	*	*	*	....	*
Tama	4	*	23,261	*	*	61,790
Union	1	*	*	*	....	*
Wapello	2	*	*	*	*	*

TABLE III Continued

County	No. of Producers	Common Brick	Drain Tile	Hollow Building Tile	Other Products[c]	Total Value
Warren	1		*	*		*
Washington	4	6,095	53,547	29,139		88,781
Webster	9	*[a]	552,421	651,552	620,460	1,823,433
Winneshiek	1	*				*
Woodbury	2	*		*	*	*
Wright	1				*	*
Counties with less than three producers		931,068	738,348	445,671	480,135	2,360,214
	115	941,489	3,127,378	2,475,291	1,563,443	8,107,601
Pottery and clay sold						17,723

*Included under: Counties having less than three producers.
[a]Included in "Hollow building tile".
[b]Includes sewer pipe.
[c]Includes: Vitrified brick or block and face brick, $629,460; sewer pipe, $902,008; miscellaneous, $31,975. The Census lists an additional miscellaneous item of $75,789.

TABLE III Continued

VALUE OF CLAY PRODUCTS IN 1920.

County	No. of Producers	Common Brick	Drain Tile	Hollow Building Tile	Other Products[a]	Total Value
Allamakee	1	*	*	*		*
Appanoose	1	*				*
Audubon	1	*		*		*
Benton	4	$ 5,840	$ 54,378	$ 19,628		$ 79,846
Boone	2	*	*	*		*
Buena Vista	2		*			*
Cass	1	*	*	*		*
Cedar	1	*	*			*
Cerro Gordo	7	24,404	1,780,811	1,014,208		2,818,423
Clinton	1	*	*			*
Dallas	5	*	330,185	746,918	*	1,082,955
Des Moines	1		*			*
Dubuque	2	*				*
Floyd	1	*	*	*		*
Franklin	2	*	*	*		*
Grundy	1	*			*	*
Hancock	1		*			*
Hardin	1		*			*
Henry	2	*	*	*		*
Howard	1	*	*	*		*
Iowa	2	*	*	*		*
Jackson	1	*		*		*
Jasper	1	*	*			*
Jefferson	2		*			*
Johnson	2	*	*			*

TABLE III Continued

County	No. of Producers	Common Brick	Drain Tile	Hollow Building Tile	Other Products[a]	Total Value
Jones	2	*	*	*		*
Keokuk	5	*	196,598	*	*	452,541
Kossuth	1		*			*
Lee	1	*			*	*
Linn	1		*			*
Louisa	1	*	*	*		*
Madison	1		*			*
Marion	4	*	92,993	146,280	*	284,527
Mills	1	*				*
Muscatine	2	*				*
Page	1	*	*	*		*
Polk	8	121,296	278,387	*	*	1,200,330
Poweshiek	4		52,061	1,287		53,548
Sac	1		*			*
Scott	2		*	*	*	*
Story	2	*	*	*	*	*
Tama	4	*	39,365		*	81,257
Union	1	*	*	*		*
Wapello	3	90,158	*	*		202,133
Warren	1		*	*		*
Washington	4	3,495	81,857	25,838		111,190
Webster	8	28,955	274,621	388,311	428,711	1,144,062
Winneshiek	1	*				*
Woodbury	3	531,383				531,383
Wright	1		*			*
Counties with less than three producers		340,651	1,492,897	706,306	1,056,173	2,397,762
	109	$1,146,182	$4,760,115	$3,048,776	$1,484,884	$10,439,957
Pottery, and clay sold						49,275

*Included under: Counties having less than three producers.
[a]Includes: Vitrified brick or block, $176,430; Face brick, $346,164; Sewer pipe, $918,669; Flue lining, $35,023; Wall coping, $8,598.

LIMESTONE AND LIME.

The amount of limestone and lime sold in Iowa in 1919 was 519,030 tons, valued at $567,356. The amount sold in 1920 was 620,665 tons with a value of $840,544. These figures show a recuperation from the depression of 1918 when the output was valued at $444,800, and reflect the improvement in business conditions. Much the larger part of the limestone output is crushed as is shown by the fact that in each of the two years a little over 379,000 tons was used in this way. The use of limestone in agriculture shows a gratifying increase, rising from 34,489 tons in 1918 to 46,452 tons in 1919 and to 67,140 tons in

1920. Insofar as this represents a necessity for reënriching wornout soils it is, of course, lamentable, but so far as it means the reclaiming of lands heretofore unsuitable for agriculture its use is extremely praiseworthy. As in previous years, so in these two, the only producers of lime were the Eagle Point Lime Works of Dubuque and the Alfred Hurst Estate of Maquoketa. One operator reported the sale of sandstone in 1920.

Iowa ranked thirty-third among the states in production of stone in 1919. She produced 0.8 per cent of the amount and 0.5 per cent of the value in that year. In the next year her rank was thirty-fourth with percentages of 0.8 of the amount and 0.6 of the value of the total production. She ranked twenty-seventh in amount of lime produced in 1919 and twenty-ninth in value. These positions were raised in 1920 to twenty-sixth in amount and twenty-seventh in value. The average value per ton in 1919 was $9.79 and in 1920, $10.80.

TABLE IV.

PRODUCTION OF LIMESTONE AND LIME IN 1919

County	No. of Producers	Building Stone	Rubble and Riprap	Crushed Stone			Other Uses[a]	Total Value
				Road Making	Concrete	Agriculture		
Allamakee	2	*	*					*
Black Hawk	2	*			*			*
Cerro Gordo	1		*				*	*
Clayton	1		*					*
Dubuque	6	*	$4,000	$10,980	$22,954	*	*	$63,084
Hardin	1			14,678		*		*
Henry	1		*		*			*
Howard	1				*		*	*
Jackson	1						*	*
Jones	2		*		*	*	*	*
Lee	3		*	*	*	*	*	56,786
Linn	1				*			*
Madison	2		*		*			*
Marshall	1			*				*
Pocahontas	1			*				*
Scott	3		*		140,186	$25,627	*	192,973
Counties with less than three producers		$1,816	79,301	34,615	151,272	5,727	$76,200	278,263
	29	$1,816	$83,301	$60,273	$314,412	$31,354	$76,200	$567,356

[a]Includes: Lime, and stone sold for unspecified uses, $58,898; stone sold for flux, railroad ballast and use in sugar factories, $17,302.

TABLE IV Continued

PRODUCTION OF LIMESTONE AND LIME IN 1920.

County	No. of Producers	Building Stone	Rubble and Riprap	Crushed Stone			Other Uses[a]	Total Value
				Road Making and Railroad Ballast	Con-crete	Agricul-ture		
Allamakee	2	*	*					*
Black Hawk	1				*			*
Cerro Gordo	2		*	*			*	*
Clayton	1						*	*
Clinton	1		*					*
Des Moines	1		*					*
Dubuque	6		$28,807	$10,343	*	*	*	$94,521
Floyd	2		*				*	*
Hardin	1				*	*		*
Henry	1		*		*			*
Howard	1			*				*
Jackson	1		*			*	*	*
Jones	3		14,605	*	*	$1,883	*	87,819
Lee	3		*		$39,531	*		63,595
Linn	1			*	*			*
Madison	1		*		*	*		*
Mitchell	1						*	*
Pocahontas	1				*			*
Scott	4		*	*	212,369	36,506	*	291,850
Counties with less than three producers		*	119,864	17,135	209,546	8,251	$127,604	537,785
	34	*	$163,276	$ 27,478	$461,446	$ 46,640	$127,604	$840,544

[a]Includes: Sandstone and lime, $90,952; limestone sold for flux, $12,902; for sugar factories, $23,750.

SAND AND GRAVEL.

Iowa produced 2,093,471 tons of sand and gravel in 1919, and this had a value of $1,383,764. The output for the next year was 2,467,644 tons valued at $1,993,441. These figures show a substantial increase in spite of handicaps of car shortage and other industrial conditions. The statistics for 1920 show for the first time the various uses for which gravel is sold. These uses for Iowa gravel are:

	Quantity tons	Value
Building gravel	256,600	$291,758
Roofing gravel	16,677	26,202
Paving gravel	499,072	521,360
Railroad ballast	191,914	46,486
	964,263	$885,806

The tonnage of the sand produced during the years 1919 and 1920 was distributed as follows:

Kinds	1919 Tons	1919 Value	1920 Tons	1920 Value
Molding sand	6,405	$ 14,318	10,566	$ 13,254
Building sand	913,400	531,596	1,058,990	788,184
Engine sand	39,891	9,230	27,334	16,366
Paving sand	165,597	86,235	205,893	152,337
Filter sand	20,242	13,224	41,084	28,130
Other sands	142,253	72,952	159,514	109,364
Railroad ballast	50,394	19,712		
Gravel	755,289	636,497	964,263	885,806
	2,093,471	$1,383,764	2,467,644	$1,993,441

Table V. shows in as much detail as possible the production of sand and gravel in the different counties in 1919 and 1920.

TABLE V.

PRODUCTION OF SAND AND GRAVEL IN 1919

County	No. of Producers	Building Sand	Engine Sand† and Railroad Ballast§	Paving Sand	Other Sand[a]	Gravel	Quantity Tons	Value
Black Hawk	5	$ 13,300	†	*	*	*	122,175	$ 62,050
Boone	1	*	†			*	*	*
Bremer	2	*		*		*	*	*
Buena Vista	1					*	*	*
Butler	1	*					*	*
Carroll	1	*					*	*
Cerro Gordo	2	*	†§	*	*	*	*	*
Cherokee	2	*	§	*		*	*	*
Clay	2	*			*		*	*
Clayton	1				*		*	*
Clinton	6	*				17,030	31,477	20,578
Des Moines	2	*		*		*	*	*
Dickinson	2	*	§				*	*
Dubuque	3	*	†			*	42,851	30,023
Emmet	2	*				*	*	*
Fayette	4	*				*	6,690	2,490
Franklin	3	7,355					5,907	7,355
Hardin	2	*			*		*	*
Humboldt	1	*	§	*	*	*	*	*
Ida	1	*					*	*
Jackson	2	*				*	*	*
Johnson	2	*		*		*	*	*
Jones	2	*				*	*	*
Lee	2	*					*	*
Linn	4	*				*	94,429	43,413
Lyon	2	*				*	*	*
Mahaska	2	*		*		*	*	*
Marion	2	*	§			*	*	*
Marshall	1	*				*	*	*

TABLE V Continued

County	No. of Producers	Building Sand	Engine Sand†and Railroad Ballast§	Paving Sand	Other Sand[a]	Gravel	Quantity Tons	Value
Montgomery	1	*		*			*	*
Muscatine	2	*	†		*	*	*	*
O'Brien	6	*				*	18,099	$5,935
Osceola	2	*					*	*
Palo Alto	2					*	*	*
Plymouth	3	*				*	31,887	20,869
Polk	14	107,877	†	35,460	5,944	103,917	378,243	258,457
Sac	2	*				*	*	*
Scott	2	*				*	*	*
Sioux	5	*				*	31,601	23,255
Story	2					*	*	*
Van Buren	1	*					*	*
Wapello	3	*	†	*	*	*	111,032	68,783
Webster	3	*				*	17,381	15,400
Winneshiek	2	*				*	*	*
Woodbury	1	*					*	*
Wright	2	*				*	*	*
Counties with less than three producers		403,064	28,942	50,775	94,550	515,550	1,323,874	887,206
	116	$ 531,596	$ 28,942	$ 86,235	$ 100,494	$ 636,497	2,093,471	$1,383,764

[a]Includes: Molding sand, $14,318; grinding and polishing, fire or furnace sand, $7,637; filter sand, $13,224; unclassified, $65,315.
*Included under: Counties with less than three producers.
†Engine sand, $9,230; §railroad ballast, $19,712.

TABLE V Continued

PRODUCTION OF SAND AND GRAVEL IN 1920

County	No. of Producers	Building Sand	Engine Sand† and Railroad Ballast§	Paving Sand	Other Sand[a]	Gravel	Quantity Tons	Value
Adair	1	*					*	*
Black Hawk	5	$ 46,800	†		*	*	84,440	$ 66,484
Boone	1	*	†			*	*	*
Bremer	2	*		*		*	*	*
Buena Vista	1					*	*	*
Butler	2	*	§			*	*	*
Cerro Gordo	1	*	†§	*	*	*	*	*
Cherokee	3	*	§		*	*	275,141	92,058
Clay	1				*	*	*	*
Clayton	1				*		*	*
Clinton	4	*	†	*		14,675	25,097	19,300
Des Moines	2	*		*		*	*	*
Dubuque	2	*				*	*	*
Emmet	2	*				*	*	*
Fayette	4	*			*	31,025	51,057	41,275
Franklin	3	3,165					8,977	3,165
Hardin	1	*					*	*
Harrison	1	*			*	*	*	*
Humboldt	1	*		*	*	*	*	*
Ida	1	*					*	*
Jackson	3	*	§			*	24,805	16,035
Johnson	3	*				*	20,557	18,210
Jones	1	*					*	*
Linn	4	*				*	101,946	63,199
Lyon	2		§			*	*	*
Mahaska	1	*		*	*	*	*	*
Marion	1	*					*	*
Marshall	1	*		*			*	*
Muscatine	4	76,964	†	*	7,570	39,140	156,100	128,908

TABLE V Continued

County	No. of Producers	Building Sand	Engine Sand† and Railroad Ballast§	Paving Sand	Other Sand[a]	Gravel	Quantity Tons	Value
O'Brien	4	7,867					6,436	7,867
Osceola	3	*	§			*	15,664	6,707
Palo Alto	1	*					*	*
Plymouth	3	*				*	22,121	18,419
Polk	12	149,669	†9,151	74,951	54,934	180,450	524,607	469,155
Sac	2	*			*	*	*	*
Scott	2	*					*	*
Sioux	5	35,940	†	*	35,000	*	79,944	77,940
Wapello	4	36,688	†	*	15,359	16,225	88,271	79,584
Webster	4	*		*		*	35,974	40,999
Winneshiek	2	*		*		*	*	*
Woodbury	1	*				*	*	*
Wright	2		§		*		*	*
Counties with less than three producers		357,093	53,701	77,386	37,885	557,805	1,511,137	844,136
	104	$ 788,184	$ 62,852	$ 152,337	$ 150,748	$ 839,320	2,467,644	$1,993,441

*Included under: Counties having less than three producers.
†Engine sand, $16,366; §Railroad ballast sand, $46,486.
[a]Includes: Molding and grinding sand, $16,502; Filter sand, $28,130; Uses not specified, $106,016.

GYPSUM.

The statement was made in the report on mineral production for 1918 that the amount of gypsum mined in Iowa in that year was 29 per cent less than in the year before and that the value of the output was 5 per cent less than in 1917. In 1919, on the contrary, the quantity mined was 28 per cent greater than that of 1918 while the increase in value amounted to 35 per cent. The tonnage of the gypsum mined in 1919 was 421,279, as compared with 327,927 in 1918. Iowa shared with other states in the return to larger production and higher prices following the postwar decline. In 1920, again, the upward trend is shown, for the tonnage in that year amounted to 571,895. Perhaps the most remarkable feature of the situation, however, is the phenomenal rise in value of finished product as shown by increase from $1,946,414 in 1918 to $2,634,444 in 1919 and $4,422,965 in 1920. The great increase is ascribed to the increased costs of production and to the large increase in the manufacture of gypsum board.

The following table presents the details of the industry for the two years here considered.

VALUE OF GYPSUM PRODUCED IN IOWA.

	1919		1920		
	Tons	Value		Tons	Value
Crude gypsum mined	421,279			571,895	
Sold crude—					
to Portland cement mills	66,619	$ 222,672		69,435	$ 252,593
as land plaster	2,405	8,760		41,404	161,838
Total sold crude	69,024	231,432		110,839	414,431
Sold calcined—					
as stucco	10,750	76,472		12,646	120,780
as mixed wall plaster	208,829	1,754,815		219,107	2,328,744
as plaster of Paris, Keene's cement, dental plaster, to plate glass works	874	11,063	Plaster of Paris	953	13,482
			Others	482	8,368
as boards, tile or block	44,203	560,662	boards	41,534	968,607
			tile &c.	46,678	568,253
			Total	88,212	1,537,160
Total sold calcined	264,656	2,403,012		321,400	4,008,534
Total value		2,634,444			4,422,965

A striking feature of the statistics is the large amount of raw gypsum which was sold in 1920 for agricultural uses. This was a much larger quantity than had been sold in any previous year. The small amount sold in 1919 was in line with conditions all over the country. The sale of raw gypsum to cement mills was about the same in Iowa during the two years. The following table shows the amounts of crude gypsum sold in the United States in 1919 and 1920 in short tons.

State	AGRICULTURE 1919	AGRICULTURE 1920	CEMENT 1919	CEMENT 1920
Iowa	2,405	41,404	66,619	69,435
Michigan	1,597	12,092	48,798	52,705
Nevada	(a)	(a)	(a)	13,043
New York	5,458	15,510	210,959	255,567
Ohio	1,435	(a)	6,290	8,474
Oklahoma	(a)	(a)	24,761	(a)
Texas	(a)	(a)	10,637	16,900
Other States	29,083	38,437	93,744	125,777
	39,978	107,443	461,808	541,901

(a) Included with "Other States".

Virginia produced nearly 50 per cent of the agricultural gypsum sold in 1919, with New York and Iowa occupying second and third places. In 1920 Iowa took first rank. Much of Virginia's output goes to the improvement of her peanut crop. The average price per ton received for agricultural gypsum in 1919 was $4.64, and in 1920, $5.19. Prices of gypsum used in cement were $2.83 in 1919 and $3.58 in 1920.

The total output of calcined gypsum in the United States during these two years was as follows:

	1919			1920		
	Sold calcined			Sold calcined		
State	Tons	Value	Total Value	Tons	Value	Total Value
Iowa	264,656	$ 2,403,012	$ 2,634,444	321,400	$ 4,008,534	$ 4,422,965
Kansas	52,994	481,561	520,673	78,347	864,334	968,298
Michigan	250,687	2,216,257	2,390,367	261,499	3,252,060	3,521,028
Nevada	63,973	474,334	497,561	105,280	1,036,158	1,100,261
New York	316,767	2,910,404	3,530,743	387,856	5,451,426	6,438,929
Ohio	219,900	2,022,987	2,049,723	220,903	2,122,223	2,161,038
Oklahoma	71,986	644,537	708,660	69,924	772,749	816,768
Texas	130,642	1,064,264	1,080,754	164,956	1,391,382	1,439,491
Wyoming	37,314	282,587	282,587	43,384	410,599	410,724
Others (a)	187,101	1,709,761	2,032,395	250,935	2,658,405	3,253,563
	1,596,020	14,209,704	15,727,907	1,904,484	21,967,870	24,533,065

(a) Alaska, Arizona, California, Colorado, Montana, New Mexico, Oregon, South Dakota, Utah, Virginia.

The production of gypsum boards and blocks has grown from 116,535 tons in 1916, valued at $246,037, an average of $2.11 per ton, to 308,756 tons in 1920, valued at $6,091,617, an average price of $19.73 per ton. The amount of gypsum used in boards and blocks in 1920 was nearly equal but the boards were valued at about twice as much as the blocks.

In 1920 the Beaver Board Company of Buffalo, New York, purchased the capital stock of the American Cement Plaster Company of Chicago, which operates a plant at Fort Dodge. The American will continue to operate its plants and manufacture the same products as in the past.

The Centerville Gypsum Company resumed operations on May 23, 1919, and operated until November 11, when work was suspended because of a labor strike. Work was resumed early in 1920 and has continued since.

The active plants operating in Iowa are: The Centerville Gypsum Company, Centerville; American Cement Plaster Division, Plymouth Gypsum Company, U. S. Gypsum Company, Wasem Plaster Company and the Cardiff Gypsum Plaster Company, all of Fort Dodge.

The annual reports of this Survey for 1917 and 1918 include a very comprehensive monograph on gypsum prepared by Dr. Frank A. Wilder, at one time State Geologist, which describes the subject in all its aspects, geologic, chemical, economic and technologic. Copies of this report are available on request.

CEMENT.

Nearly every producing state in the Union showed an increase in the production of Portland cement in 1919 over 1918, but Iowa proved to be the one exception. The increases ranged from 6 to 37 per cent while the Iowa output fell off 1 per cent. However, during the same period the shipments increased by 43 per cent in Iowa, while the average increase for the nation was 21 per cent. This condition was reversed in 1920, for the Iowa production of that year exceeded that of 1919 by 36 per cent, while shipments were 3 per cent less in 1920. The detailed figures are given below.

	1918	1919	1920
Production, bbls.	3,626,455	3,573,278	4,849,228
Stock, Dec. 31, bbls.	1,055,540	126,162	553,607
Shipments, bbls.	3,188,669	4,569,110	4,421,783
Shipments, value	$5,423,926	$7,798,347	$8,742,854
Ave. factory price per bbl.	$1.70	$1.71	$1.98
Consumption, bbls.	2,298,157	3,362,263	3,360,089
Population, est.	2,224,771	2,404,021	2,422,485
Est. consumption per capita, bbls.	1.03	1.40	1.39

Of course the Lehigh district of eastern Pennsylvania and western New Jersey is the greatest producing district in the United States, producing about one-fourth of the Nation's total, from twenty plants, but it is worthy of note that Iowa, a relatively new producer, and in an agricultural region, stands eighth among the states and that the geographic district in which Iowa is grouped, and which includes Minnesota and Missouri, produces nearly one-eighth of the total output. It is excelled only by the Lehigh district and by the Illinois and western Indiana district. The 1920 production of these three districts in barrels was: Lehigh, 25,417,804; Illinois and western Indiana, 13,106,011; Minnesota, Iowa and Missouri, 12,406,745. The four Iowa plants have an annual capacity of 5,350,000 barrels. It will be seen that this capacity was not nearly reached in the production of either year here discussed. The production in the ten leading states is shown in the following table:

State	Active plants		Production		Shipments	
			Quantity	Barrels	1919	
	1919	1920	1919	1920	Quantity barrels	Value
Pennsylvania	21	21	25,325,173	28,269,314	26,250.077	$ 43,126,528
Indiana	5	6	7,262,454	10,787,751	7,667,976	12,527,770
California	8	9	4,642,679	7,098,084	4,743,336	8,860,196
Missouri	5	5	5,216,347	6,017,517	5,496,164	9,264,017
New York	8	9	4,383,579	5,885,058	4,441,250	7,700,406
Illinois	4	4	4,206,918	5,538,558	4,873,831	7,901,689
Michigan	11	11	4,675,244	4,891,457	4,990,308	8,468,196
Iowa	4	4	3,573,278	4,849,228	4,569,110	7,798,347
Kansas	7	7	2,927,270	4,340,794	3,023,901	5,467,284
Texas	3	5	2,249,735	2,562,208	2,318,747	4,226,222
Total for U. S.	111	117	80.777.935	100.023.245	85.612.899	146.734.844

State	Shipments, Cont. 1920 Quantity barrels	Value	Average factory price per barrel 1919	1920	Consumption 1919 Barrels	Per capita	1920 Barrels	Per capita
Pennsylvania	27,662,116	$ 52,632,082	$1.64	$1.90	7,571,085	.87	8,582,057	.97
Indiana	10,191,126	18,649,115	1.63	1.83	3,135,162	1.07	2,935,056	.99
California	7,064,010	15,449,645	1.87	2.19	3,900,436	1.14	5,832,977	1.65
Missouri	5,605,952	10,980,453	1.69	1.96	1,932,119	.57	2,525,087	.74
New York	6,049,150	12,206,698	1.73	2.02	7,078,888	.68	8,663,051	.82
Illinois	5,148,040	10,012,158	1.62	1.94	6,154,227	.95	7,407,388	1.13
Michigan	4,442,455	10,939,633	1.70	2.46	5,097,575	1.39	5,142,945	1.37
Iowa	4,421,783	8,742,854	1.71	1.98	3,362,263	1.40	3,360,089	1.39
Kansas	4,158,399	8,649,157	1.81	2.08	1,900,921	1.07	2,341,323	1.32
Texas	2,626,130	5,898,972	1.82	2.25	1,981,500	.42	2,450,278	.52
Total for U. S.*	96,311,719	$194,439,025	$1.71	$2.02	88,814,535	.77	94,001,085	.86

*Other producing states are: Alabama, Colorado, Georgia, Kentucky, Maryland, Minnesota, Montana, Nebraska, New Jersey, Ohio, Oklahoma, Oregon, Tennessee, Utah, Virginia and West Virginia.

It seems that the relation between production or shipments and consumption is not very close, either as to the total used or as to per capita consumption. Iowa ranks ninth in total consumption and fourth in per capita amount. The lowest rank for per capita consumption is held by Mississippi with a figure of 0.15 barrel, while the highest rank is that of Arizona whose consumption is 1.86 barrels per inhabitant. The greatest consumer, naturally, is New York, with Pennsylvania, Illinois, Ohio and California succeeding in the order named.

The figures for the production of concrete stone and block in Iowa are combined in part with those for Kansas, to avoid revealing individual production. However, these figures show that as in previous years Iowa is one of the leading states in the manufacture of these products. In 1919 she ranked fourth and in 1920 had risen to first place. The data are given in the table below. Of course the values here given are not to be included in total values for the state as both cement and aggregate have been accounted for elsewhere.

Kind	1919 Quantity Cu. ft.	1919 Value	1920 Quantity Cu. ft.	1920 Value
Architectural stone	27,315[a]	$ 45,487[a]	6,358	$ 12,873
Concrete blocks	1,368,639	431,254	888,663	402,606
Concrete brick	9,655	4,496	10,633	6,276
Silo blocks and staves	136,470[a]	82,898[a]	66,330	60,994
Miscellaneous		176,561		914,517
Total		$706,146	971,984	$1,397,266

(a) Includes figures for Kansas.

The total production of these materials for the United States was $7,901,105 in 1919 and $9,899,576 in 1920. Ohio, Illinois, Indiana, Iowa and Michigan were the five leaders in 1919, with rank as given, and Iowa, Ohio, Minnesota, Indiana and Illinois were the chief producers in 1920, in the order given.

MINERAL WATERS.

The reported output of mineral waters sold in Iowa for table or medicinal use in 1919 was 39,661 gallons, valued at $5,703, as compared with 87,703 gallons sold for $3,937, in 1918. These figures show a decrease in quantity of 55 per cent but an increase in value of 45 per cent. The 1919 output came from four springs: Fry's and the Grand Hotel at Colfax, Hawkeye Hygeia at Sioux City, and Lime Rock at Dubuque. The average price received rose from four cents in 1918 to fourteen cents per gallon in 1919. In addition these springs and the Crystal spring of Estherville used 321,500 gallons of water for soft drinks.

The output for 1920 was a little less than that for 1919. The table and medicinal water sold amounted to 38,877 gallons, valued at $3,419. This represents a decrease of 2 per cent in quantity and 40 per cent in value, as the average price received was only nine cents per gallon. The water used for soft drinks amounted to 197,183 gallons. The list of producing springs was the same as that of 1919, with the addition of the Egralharve Mineral Spring at Okoboji, which was not used the preceding year.

POTASH.

The statistics for 1919 include 89 short tons of potash (K_2O)

with a value of $20,025. This was derived from Steffens waste water at beet sugar factories. No production was reported for 1920.

NATURAL GAS.

The production of natural gas from shallow wells in the glacial drift was continued during the years here discussed and amounted in 1919 to 740,000 cubic feet with a value of $185 and in 1920 to 827,000 cubic feet valued at $290. All was used locally, as none is carried to any distance for consumption. The average price is twenty-five cents per thousand cubic feet.

PETROLEUM AND NATURAL GAS IN IOWA

BY

JESSE V. HOWELL

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PETROLEUM AND NATURAL GAS IN IOWA

PART I.

GEOLOGY OF OIL AND GAS

The enormous increase in the use of the products of petroleum during the past few years, with its attendant rise in the price of these commodities, has stimulated a world-wide search for new oil fields. No part of the inhabited globe seems to have escaped the efforts of the prospector and Iowa, too, has had her share of them. At the present time there are being drilled within the confines of the state no less than a half dozen tests for oil and gas. In view of the very general interest in these matters, it seems advisable to sum up all available information which has a bearing on the problem of whether or not the rocks of Iowa contain workable deposits of the natural hydrocarbons.

ORIGIN OF OIL AND GAS

The theory that oil and gas are of organic origin, and have resulted from the exceedingly slow decomposition or distillation of organic matter buried in the rocks, is now almost universally accepted by geologists. Field evidence is overwhelmingly opposed to the idea that the natural hydrocarbons are of volcanic origin, or that they have been developed chemically from some inorganic materials.

Evidence now at hand indicates that petroleum has been formed in marine sediments from the remains of animals and plants, deposited in the quiet waters outside of the littoral zone, where they have been prevented from rapid decay by the presence of salt in the sea water. Anerobic bacteria probably have been effective agents in producing the decomposition of the buried organic material, and they, together with dynamic metamorphism, have produced a change into hydrocarbons.

ACCUMULATION OF OIL AND GAS

The factors which seem to have the greatest influence on the presence or absence of oil in a given region are treated briefly below.

Character of the Rocks:

1. Marine or brackish water deposits. Oil and gas are known to be indigenous only to beds which can be shown to have been laid down in the sea or in brackish water lagoons near the coast.
2. Black, blue, brown, green shales with interbedded porous beds. It is only in the darker colored shales that sufficient organic material is present to provide a source of hydrocarbons.
3. Rocks deposited roughly within 100 miles of former* land areas. It seems improbable that organic material would be likely to drift beyond this distance.
4. Presence of a suitable reservoir. Contrary to the popular conception, oil and gas do not accumulate in underground caverns, but rather in porous beds of limestone or sandstone. It is necessary, therefore, that the strata include such a porous bed to retain the oil.

In order to seal this bed against the escape of the hydrocarbons, it is necessary also that above the reservoir there be an impervious layer, of either shale or dense limestone. Or in some cases a very tightly cemented sandstone may suffice.

Finally, the porous reservoir must not outcrop at the surface within a reasonable distance. This may vary from a few hundred yards to several miles, dependent upon the nature of the reservoir rock and the attitude of the beds.

Dolomites sometimes act as reservoirs of oil and gas in localities where their porosity is sufficiently high. This is especially true in the fields of Ohio and Indiana, where it has been determined that, no matter how favorable the structure may be, oil will not accumulate in the Trenton formation unless the dolomite ($MgCO_3$) content reaches 25 per cent. Rocks in which the amount of $MgCO_3$ present is below this quantity do not have the requisite porosity which will enable them to act as reservoirs.

The thickness of either a sandstone or porous dolomite may also be a factor which must be taken into consideration. Extremely thick horizons, though having the requisite porosity,

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*This statement, together with much of the accompanying discussion, has been taken from an article by Schuchert, Amer. Inst. Min. Eng. Bull. 155, pp. 3059-60, 1919.

may fail of being good reservoirs by reason of their great thickness. Thick and porous horizons afford excellent opportunity for movements of both water and hydrocarbons, and may thus prevent accumulation.

Sandstones are the most common reservoirs of oil and gas. This is true for many reasons, of which the most pertinent are (a) their high porosity, and (b) their frequent occurrence in association with the shales which presumably give rise to hydrocarbons and which also seal the sands against loss of oil and gas which find their way into them. Sandstones are the important reservoir rocks in a majority of the great oil fields of the world.

Age of the Rock.—Oil and gas have been found in rocks of all ages from the Cambrian to the Pleistocene. The oil in Europe and Asia comes almost wholly from beds of Cenozoic age, and in South America, Central America and Mexico from Mesozoic and Cenozoic beds. In North America both oil and gas occur in Paleozoic, Mesozoic and Cenozoic beds in various parts of the continent.

No important production has ever been recorded from the Cambrian, the only known occurrences in this series being a little gas in New York. The Ordovician rocks are important producers in Ohio, Kentucky, Tennessee, Illinois, Indiana, Kansas and Oklahoma. The Silurian is productive in the Appalachian field, in Ontario and in a few wells in Garvin county, Oklahoma. Oil occurs in the Devonian in the Appalachian fields, Indiana, Ohio and Ontario.

The Mississippian is productive in the Appalachian district, Kentucky, Illinois, Oklahoma and northern Texas. The Pennsylvanian series constitute the most important producing horizon in the great Mid-Continent fields of North Texas, Oklahoma and Kansas. They are productive also in Illinois, Wyoming and the Appalachian region. The Permian produces important amounts of oil and gas in Oklahoma.

The Lower Cretaceous (Comanche) is not an important producing series, but has been found to contain small amounts of oil in a few places in southern Oklahoma. The Upper Cretaceous contains large amounts of oil in east Texas, Louisiana and Wyoming.

The Tertiary beds furnish the oil in the great fields along the Gulf Coast of Texas and Louisiana, and those of California.

Small amounts of gas have been reported from Pleistocene deposits in various parts of the country, notably in Utah, Illinois and Iowa. In none of these localities does it occur in important amounts.

The accompanying table (adapted from Emmons) shows graphically the geologic distribution of oil and gas:

AGE OF PRINCIPAL PETROLEUM RESERVOIRS IN THE UNITED STATES.

(Modified after Emmons.)

	New York	Pennsylvania	West Virginia	Ohio	Kentucky	Tennessee	Indiana	Illinois	Missouri	Kansas	Oklahoma	Arkansas	Texas	Louisiana	Wyoming	Montana	California
Pleistocene																	+
Pliocene																	+
Miocene																	+
Oligocene													+	+	+		+
Eocene												+		+			+
Upper Cretaceous												+	+	+	+	+	+
Lower Cretaceous											+					+	
Jurassic																	
Triassic																	
Permian										+	+		+		+		
Pennsylvanian		+	+	+	+		+	+	+	+	+	gas	+		+		
Mississippian		+	+	+	+	+	+	+		+	+		+				
Devonian	+	+	+	+	+	+	+				+?						
Silurian	gas			+	+	+	+	+			+						
Ordovician	gas			+	+	+	+	+		+	+						
Cambrian	gas																

Degree of Metamorphism.—The heat and pressure attending dynamic metamorphism cause marked alteration of the rocks on which they act. Hydrocarbon compounds are particularly sensitive to such forces. By these means organic matter may be changed into solid, liquid or gaseous hydrocarbons, and the hydrocarbons themselves be greatly modified.

Recent work by White[1] and others has shown that a close relationship exists between intensity of regional metamorphism, measured by the extent of devolatilization of organic matter, and the occurrence of oil and gas in rocks which have been so metamorphosed. White has shown that where metamorphism has so far proceeded that the coals present contain more than sixty-five per cent of fixed carbon (pure coal basis), commercial deposits of oil have not been, and probably will not be found. A majority of the oil fields of this country occur in regions where the fixed carbon percentage is between forty-five and fifty-five.

Studies of the fields of North Texas and Oklahoma by Fuller[2], and of West Virginia by Reger[3] have substantiated White's views and have served to place the carbon ratio as a valuable indicator of petroleum possibilities in regions where the presence of coal renders it applicable.

Examination of some eighteen hundred analyses of Iowa coals, from nearly every producing county in the state have resulted in the map (Plate I) on which have been drawn "isovols", or lines indicating equal percentages of fixed carbon. Inasmuch as Iowa lies well out in the great Pennsylvanian "Prairie Syncline", and is remote from any important area of crustal disturbance, the results of such a study are less satisfactory than had been hoped. This very fact may, however, be of great importance, as will be shown later. Superficially the analyses of Iowa coals show that the entire Pennsylvanian area of the state lies between the isovols of forty-five and sixty, therefore being possibly petroliferous, according to this theory.

Examination of the carbon ratio charts for Texas, Okla-

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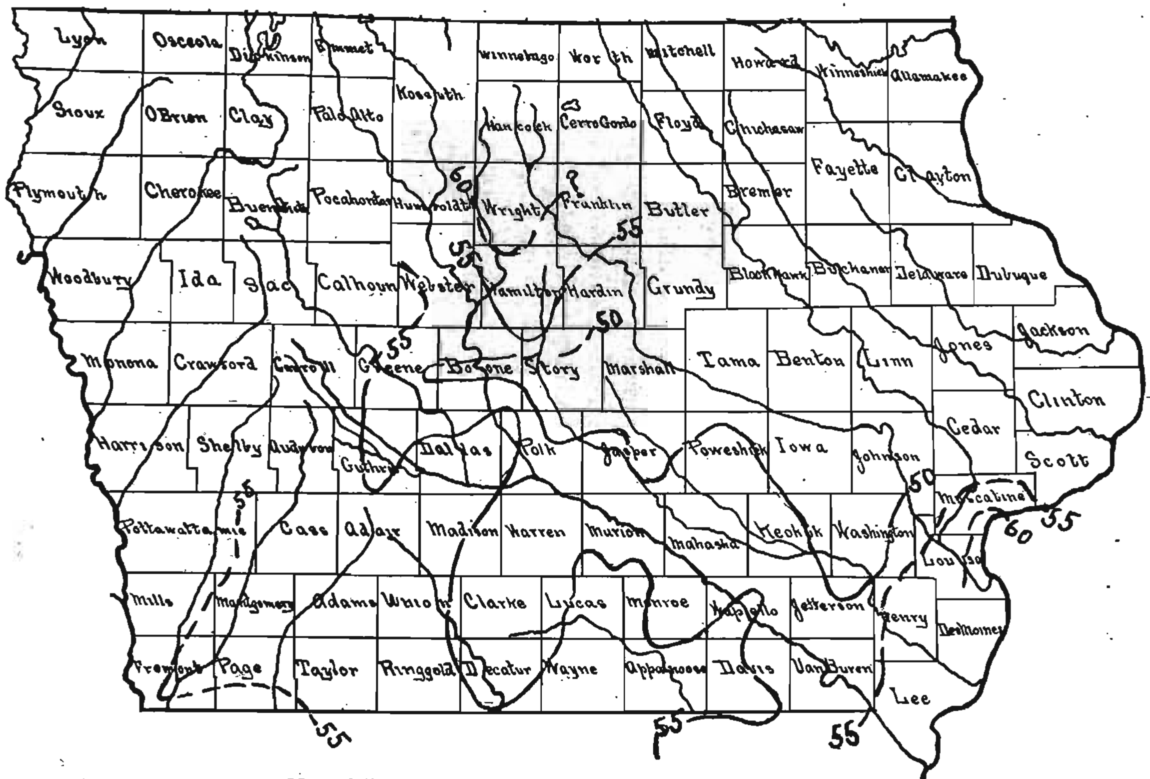
[1]David White, Bull. Geol. Soc. Amer., Vol. 28, pp. 727-734, 1917. Jnl. Wash. Acad. Sci., Vol. 6, pp. 189-212, 1915.

[2]Myron L. Fuller, Econ. Geol., Vol. 14, pp. 536-542. 1919.

[3]Reger, David B., Trans. Amer. Inst. Min. Eng.



Map of Iowa showing carbon ratios of Pennsylvanian coals homa and West Virginia (cited above) shows, however, that the productive areas in those states lie between the isovols of forty-five and sixty, but in proximity to areas whose ratios are very much higher. Such a relationship seems to have been overlooked hitherto, but it appears that it is more than mere accident. In any event, such contiguous areas of high metamorphism are lacking in Iowa.

In summary it may be said that in Iowa the evidence of the carbon ratio is rather favorable than otherwise, but owing to lack of any marked deformation which can be called on to account for the metamorphism which is indicated, it may be suspected that some important factor, operative in the Mid-Continent and Appalachian fields, may be lacking here. So far as the carbon ratio can be taken as a criterion, oil may be present in the rocks of Iowa.

MOVEMENT OF OIL AND GAS THROUGH ROCKS.

If the theory be accepted that oil and gas are of organic origin, and formed by the almost infinitely slow distillation of the animal and vegetable remains deposited in marine sedimentary rocks, the question arises as to how they become concentrated in the great pools from which they are produced. Certainly the enormous quantities of oil found in a comparatively small area in such pools as Cushing, Eldorado, Burkburnett, Salt Creek and others, are not now found in the place where they originated.

It has long been known that water moves with considerable freedom through the more porous rocks, such as sandstone and dolomite, and with greater difficulty through the more impervious ones, such as shales, quartzite, and granite. It is in this way that the water of springs and wells finds its way from the point where it falls on the surface, to that at which we utilize it. In similar manner, oil and gas have migrated through the rocks, seeking always the easiest channels through the more porous beds, where movement is freest. Three forces seem to have been effective in producing movement of the hydrocarbons; capillarity, hydrostatic pressure, and differing specific gravity of oil and water. The exact role of each of these is yet a matter of dispute among geologists, but the fact that movement has been effected does not admit of doubt.

Inasmuch as the surface tension of oil is but one-third that of water, the latter tends to fill the smaller openings in rocks, thus forcing the oil into the larger ones, such as the pore spaces in sands and porous dolomites. It is in these coarser rocks, too, that ground water circulation is most rapid, and that the oil can move most readily. Hence the oil as it is formed, tends to move from shales and other fine-grained rocks into the easier channels, through which it may be impelled upward, downward, or laterally by the agencies mentioned above. The migration may follow a single porous bed, or by means of faults, joints or fissures may cut across from one bed to another. But when oil has once left the shale in which it was formed, it finds insurmountable difficulties in the way of a return, and the shales thereafter form barriers to its passage.

Structure.—Marine sedimentary rocks were originally deposited in layers which were nearly horizontal, or had only a slight dip seaward. Subsequent movements have modified this original simple structure to a greater or less extent, the rocks being in many places wrinkled or folded, and in others fractured and faulted. The structural relations of the beds are of great importance to the oil geologist, for it has been found that nearly all oil and gas pools have accumulated in their present places as a result of favorable structural conditions.

It has been shown that oil tends to migrate through porous beds and along larger openings, such as fissures. Due largely to the lower specific gravity of the oil, it tends to move upward rather than downward, and its migration, therefore, is up the dip. This movement continues until the outcrop has been reached, unless the movement is interrupted by some barrier. Of these barriers the most common is the anticline, a form of trap which is responsible for at least 75 per cent of the oil pools in the Mid-Continent fields.

The various types of structural conditions which may cause oil and gas to accumulate are shown in the accompanying figures (figs. 1-5).

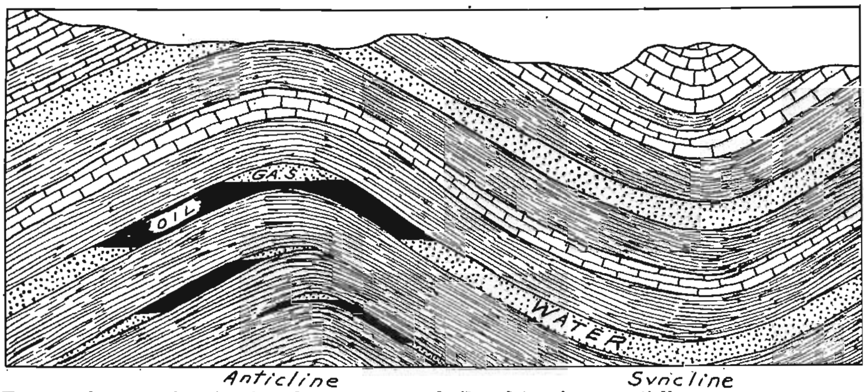


FIG. 1.—Cross section showing the occurrence of oil and gas in an anticline.

Anticlines.—An anticline is an upfold in the rocks (fig. 1) and is the commonest form of trap. On geological maps it is represented by contours, drawn on some selected bed, as in figure 2. As a rule the gas accumulates in the highest part of the fold with the oil immediately below.

Synclines.—A syncline is complementary to an anticline, and is the reverse of it. Oil accumulates in synclines only in the absence of water, or under some other special condition. Very few pools are found in synclines.

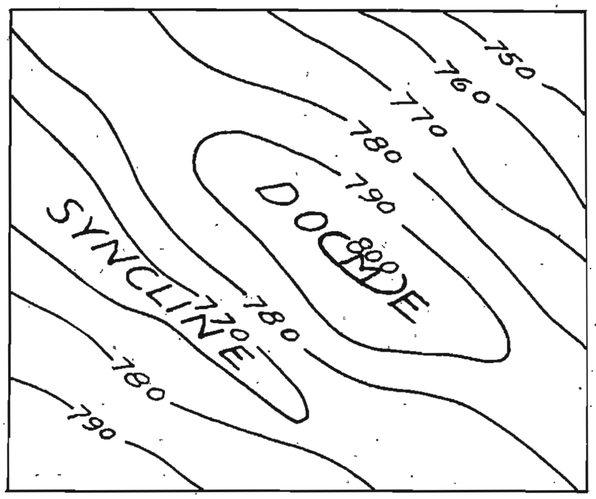


FIG. 2.—Structure contour map of a dome and a syncline.

Domes.—Anticlinal structures in which the strata dip away from the center in all directions are called domes, and constitute ideal traps. Such folds are common in Wyoming and in Osage county, Oklahoma (fig. 2).

Noses.—A plunging anticline or nose is the term applied to the structure shown in figure 3.

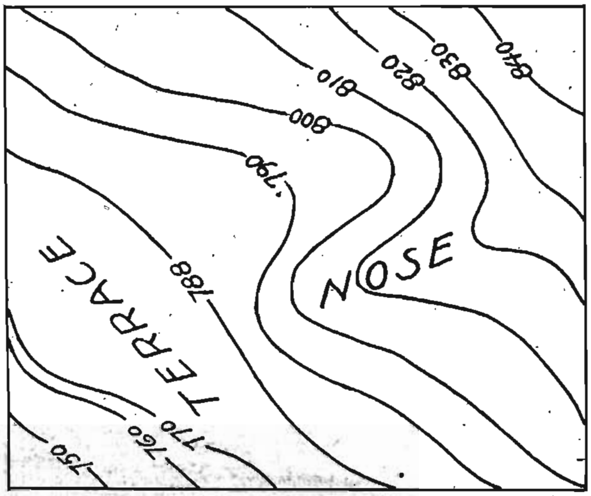


FIG. 3.—Structure contour map of a nose and a terrace.

Noses have caused accumulation in parts of Kansas and Oklahoma.

Faults.—A fault may cause accumulation when the porous bed along which the oil is moving, has been faulted against

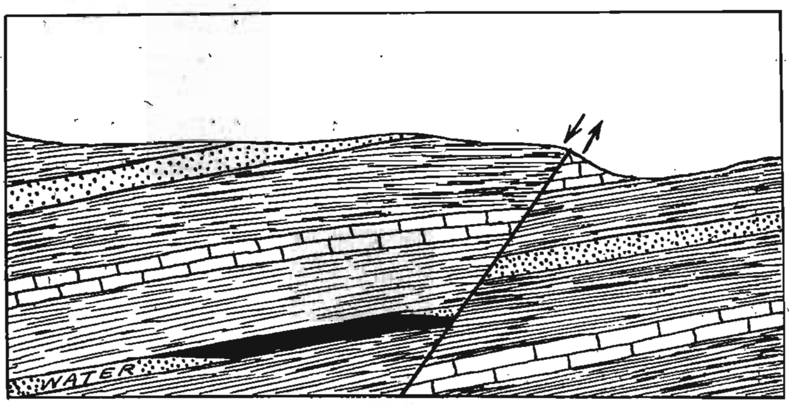


FIG. 4.—Sketch showing how faulting of the strata may cause accumulation of petroleum.

an impervious bed and sealed. Also in the case of large faults where a thick band of gouge has been produced along the fault plane, accumulation may occur (fig. 4).

Lenticular Sands on Monoclines.—In certain formations, notably the Cherokee shale, conditions of sedimentation were very irregular and it thus happened that while sand was being deposited in one place, shale was deposited on all sides. As a result lenticular masses of sandstone, often of great extent, are completely surrounded by impervious shales. Such a lens may act as a trap (fig. 5).

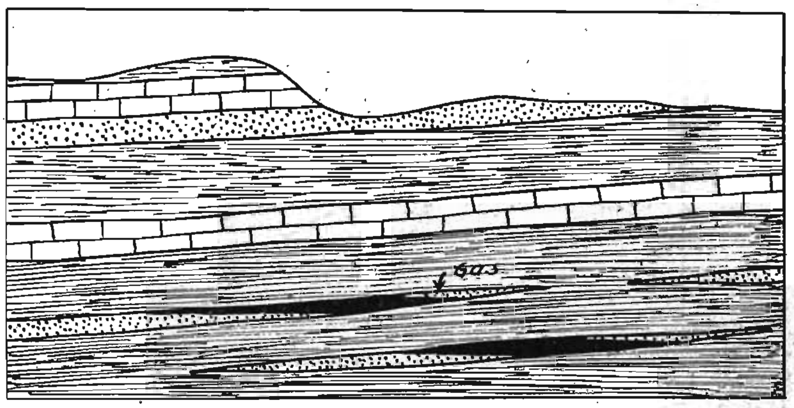


FIG. 5.—Section showing how oil and gas may accumulate in lenses on a monocline.

Other Structural Types.—Less common, and unlikely to occur in Iowa, are accumulations of hydrocarbons in salt domes, as a result of sealing by igneous dikes, in the vicinity of volcanic plugs, and along unconformities. These will not be discussed here.

Relation of Ground Water to Accumulation.—Rocks of all geologic ages contain water in greater or less amounts, and this has been termed "ground water". Its movements through the rocks and its immiscibility with oil and gas have combined to render it an important accumulative agent. If the rocks of a given region contain no water, one must search for oil in the synclines. If the rocks are saturated, the oil can be expected in structures of anticlinal type.

The direction of movement of ground water also may be a matter of great importance, for in some cases the direction of movement of the migrating hydrocarbons has been thus governed.

The mineralization of the waters also is related to the presence or absence of oil and gas. While fresh water sands occur in all oil fields, it is not unusual to find slightly mineralized water directly associated with oil. The water which lies below and behind the accumulated oil and gas in the Mid-Continent field is almost all highly mineralized, its most prominent constituent being sodium chloride, or common salt. Whether these saline waters are "fossil sea water", enclosed since the deposition of the rocks themselves, or are the product of some reaction related to the formation of the oil, is not definitely known. The almost universal association of the two is, however, a matter of common and sad knowledge to all oil operators.

SURFACE INDICATIONS OF OIL AND GAS.

Oil Seeps and Springs.—The most common and noticeable indications of oil in many fields are the seepages and oil springs. These indications have led to the discovery of important pools in Mexico, South America, Russia and Wyoming. Such indications, however, are not prominent in the fields of North America, and in the Mid-Continent fields they are almost wholly lacking. While oil springs are in most cases favorable indications, they may be in other instances, unfavorable. Sometimes they are merely evidences that oil has been present, but has made its escape.

Bituminous Rocks.—Outcrops of rocks carrying tarry and bituminous materials are often considered favorable indications, but more often indicate that hydrocarbons have been present, and have been largely lost through evaporation, leaving only the heavy residue.

Oil Shales.—Oil shales, as the term is generally used, are a clayey material, containing a greater or less quantity of a complex substance known as Kerogen, which is not itself oily. When it is heated Kerogen is changed into a mixture of various hydrocarbons of the petroleum series. Oil shales differ from Bituminous shales in that they contain no substances which are soluble in chloroform and ether.

Oil shales are not, in themselves, indications of the presence of oil. In fact they usually indicate that the processes which produce oil from organic material have not progressed sufficiently to form petroleum.

Coal Beds.—It is commonly believed that the presence of coal indicates also the presence of oil at a greater depth. This belief, no doubt, arises from the fact that in the Appalachian fields the producing oil sands are reached by drilling through the beds which produce coal. Between the coal beds and oil beds, however, there is a great thickness of barren rock. There is no relationship in origin between oil and coal, and in fact the presence of one usually is evidence that the other is absent.

Artesian Wells.—The conditions necessary to produce artesian and flowing wells are such that oil and gas can not be expected in proximity to them. Artesian wells are located in synclines, and owe their tendency to flow to hydrostatic pressure. Hydrostatic pressure is effective only in rocks which are completely filled with water.

False Indications.—There are many phenomena which in themselves are in no way related to oil and gas, but which have been associated in the minds of many people with the presence of deposits of these substances. Among the most common of these is the escape from stagnant ponds of certain gases which may result from decomposition of materials buried there. The two commonest gases produced in this way are carbon dioxide and methane (CH_4). If one stirs with a stick the sediment on the bottom of almost any marsh, bubbles of gas will rise to the surface. This gas will be found to originate from decaying leaves on the bottom of the marsh, and has no other significance.

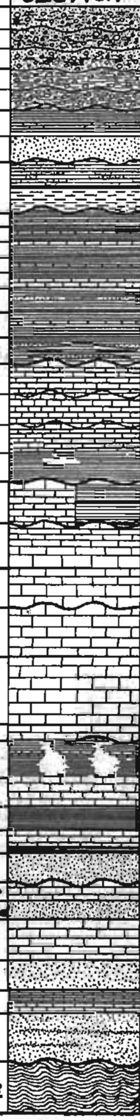
Another common mistake is that of assuming the iridescent scum on certain springs and pools to be oil. Such films are especially common in the vicinity of coal mines and coal outcrops. In most cases the films are composed of iron oxide and limonite, which have been formed by oxidation of iron salts contained in the water. An easy method of determining whether a scum is oil or iron oxide is to stir it gently with a stick. If the scum is oil it can not be broken up, whereas if it is iron oxide it will be broken in every direction and the pieces will not again join when the stirring ceases. Another test is to wet the fingers with the scum, and then wash them in water. The iron oxide washes off readily, while the oil leaves the fingers greasy.

Within the past few years a number of embryo oil booms have been started in various parts of the country by the finding of oil in water wells. In nearly every case the oil is found to be a clear, almost colorless substance and is found to have the odor of gasoline or kerosene. Upon investigation such oils are always found to have leaked out from some nearby storage tank, and to have found their way into the wells through the porous surface beds. Any oil which has a marked odor of gasoline or kerosene and which is nearly colorless, should be viewed with suspicion, especially if it be found in wells near where refined oil is stored. Natural petroleum is usually dark in color, and in no way resembles refined oil.

Few wells have ever been drilled in which there were no showings of oil, if one may credit the uninformed observers who may have watched them. Many dark colored shales contain sufficient organic materials to cause a slight greasy appearing scum to form on the mud which comes out of the hole. This is so called "Farmers Oil", which never is mistaken for petroleum by any except a novice. Another source of error is the presence in mud bailed out of the test wells of a considerable amount of oil used originally to lubricate the drilling machinery and which has accidently found its way into the well. Such oil may be dark in color and at first glance resemble true petroleum, but it can be readily distinguished by the expert. Where a well is being drilled by the rotary method, especially large quantities of lubricating oils are used on the machinery, and the mud discharged seldom is free from a little grease.

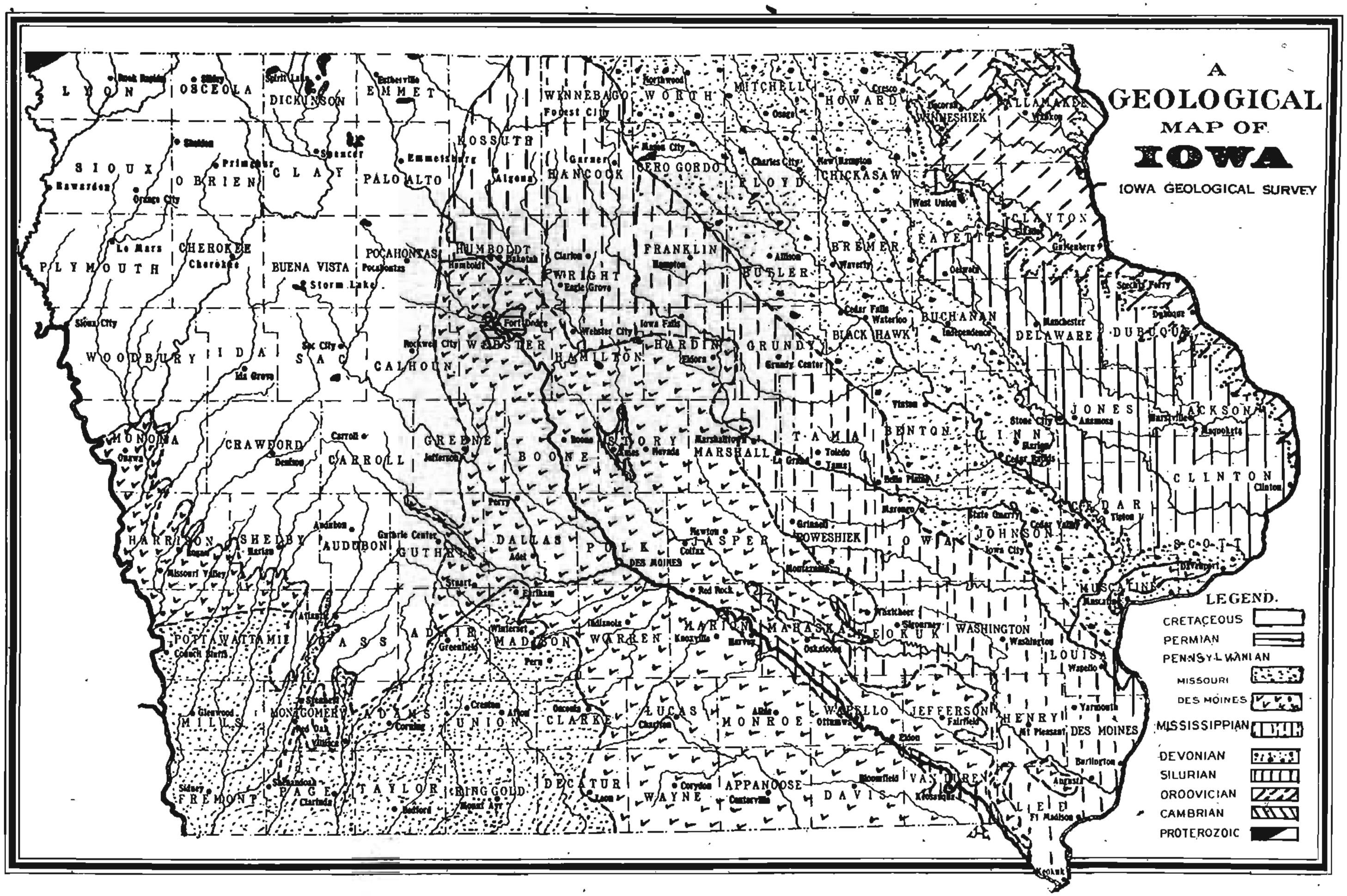
Among the minor erroneous ideas which are current are those which hold that oil occurs along creeks or rivers; that it is more apt to occur under hills, and that oil may be expected in certain regions because the topography resembles that of some producing field. The character of vegetation, the elevation above sea level, the occurrence of such features as sinkholes, have no value as indications of the presence of, or

IOWA GEOLOGICAL SURVEY PLATE II



System	Series	Formation	Columnar Section	Thickness Feet	Character of Rocks
Pleistocene	Wisconsin				
	Iowan				
	Illinoian				
	Kansan				
	Nebraskan				
Cretaceous	Upper Cretaceous	Colorado		150	Shales, with soft chalky limestones
		Dakota		100	Sandstone
Permian		Fort Dodge		50	Sandy shale and sandstone
				30	Gypsum
Pennsylvanian	Missouri	Wabaunsee		108	Shale and limestone
		Shawnee		233	Limestone and shale
		Douglas		26	Limestone and shale
		Lansing		34	Limestone and shale
		Kansas City		131	Limestone and shale
	Des Moines	Pleasanton			Shale and sandstone
		Henrietta		750	Shale and sandstone
		Cherokee			Shale, sandstone, coal.
Mississippian	St Genevieve	Pella		0-40	Limestone
	Meramec	St Louis Spergen		35-105	Limestone
	Osage	Warsaw Keokuk Burlington		150-215	Limestone
	Kinderhook			150	Shale and sandstone
Devonian	Upper Devonian	State Quarry — Lime Creek		40—120	Limestone Shale
		Cedar Valley		100	Limestone, shaly limestone. Some dolomite in the northern counties.
	Middle Devonian	Wapsipinicon		60-75	Limestones, shales and shaly limestones.
Silurian	Niagaran	Gower		120	Dolomite
		Hopkinton		220	Dolomite Very fossiliferous in places.
	Alexandrian			0-40	Limestone and dolomite.
Ordovician	Cincinnatian	Maquoketa		200	Dark shales, shaly limestones, and locally, beds of dolomite.
	Mohawkian	Galena		340	Dolomite chiefly, In places unaltered limestone.
		Decorah		0-40	Shales with thin beds of limestone
		Platteville		90	Marly limestones and shales.
	Canadian	St. Peter		80-160	Sandstone
		Prairie du Chien: Shakopee		20-80	Dolomite
		Prairie du Chien: New Richmond		20	Quartzitic sandstone
		Prairie du Chien: Oneota		150	Dolomite
Cambrian	Croixan	Jordan		100	Coarse sandstone
		St Lawrence		50	Dolomite, sandy
		Dresbach			Sandstone, with bands of glauconite
Algonkian	Huronian	Sioux Quartzite			Quartzite

Columnar section of Iowa rocks.


A
GEOLOGICAL
MAP OF
IOWA
IOWA GEOLOGICAL SURVEY
LEGEND.
CRETACEOUS
PERMIAN
PENNSYLVANIAN
MISSOURI
DES MOINES
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PROTEROZOIC
LYON
OSCEOLA
DICKINSON
EMMET
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
SIOUX
O'BRIEN
CLAY
PALO ALTO
HANCOCK
CERRO GORDO
FLOYD
CHICKASAW
CLAYTON
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
FAYETTE
WOODBURY
IDA
SAC
CALHOUN
WEBSTER
HAMILTON
HARDIN
GRUNDY
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
CLINTON
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
CEDAR
SCOTT
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
MUSCATINE
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE
DES MOINES

absence of oil. Neither does the occurrence on the surface of certain kinds of pebbles or gravel, or the occurrence of fossils indicate the presence of oil. The only way by which surface observations can give a clue to the conditions in depth is that which is used by the geologist and which will be described subsequently.

GEOLOGICAL CONDITIONS IN IOWA.

The Geologic Section.—The rocks exposed at the surface in Iowa include representatives of every series from the Algonkian through the Paleozoic. The Mesozoic is represented only by the Cretaceous which covers a comparatively small area in the western part of the state. All of these rocks are covered with a thick mantle of glacial drift, and hence they are to be seen only along streams where the rivers have cut through the mantling materials. The oldest rocks, representing the Algonkian, outcrop in a very small area in the extreme northwest corner of the state and the strata of the Cambrian system, the oldest of the Paleozoic rocks, outcrop in the northeast corner. The succeeding beds of the Paleozoic outcrop in nearly parallel belts successively to the southwest, their strike being generally northwest-southeast. A better idea of the conditions can be obtained by examining the Columnar Section (Plate II) and the Geological Map (Plate III).

Possible Petroliferous Horizons—The best clue to a horizon which might be found productive in the state is found by studying conditions in nearby states which already produce oil. The lowermost horizon represented in Iowa which has ever proved productive elsewhere, is the Ordovician. In this system is found the Trenton formation from which important production is obtained in Indiana, Ohio, Kentucky and Ontario. In these fields the producing sand is porous dolomite. It corresponds stratigraphically with the Galena and Platteville of Iowa. Production is obtained only at points where the content of $MgCO_3$ is greater than 25 per cent, the reason for this being that only when the percentage rises above this amount, is the porosity of the rock great enough to permit it to act as a reservoir.

In certain parts of the Appalachian fields and in Ontario, sandstones of Silurian age are productive of gas and oil. The Silurian is represented in Iowa by a thick series of limestone and dolomite. In the Colmar field of Illinois a small amount of oil has been obtained also from irregular sands at the contact between the Ordovician and the Silurian systems.

In the Appalachian region and as far west as Indiana, oil and gas have been produced in Devonian rocks. This system is represented in Iowa, but the character of the rocks makes it extremely unlikely that oil will be found there.

In Illinois, Oklahoma, Texas and the Appalachian district rocks of the Mississippian age have produced large quantities of oil. The Mississippian rocks of Iowa are of similar character.

The great oil producing series in the Mid-Continent fields is the Pennsylvanian, and one of its most productive horizons is the Cherokee shale. The Pennsylvanian is extremely well developed in Iowa, and the Cherokee member is present there also. The Permian and Cretaceous have produced oil in various parts of North America. Rocks of these ages are present in Iowa, but their distribution and character are such that one is not justified in expecting to find oil or gas in them here. The glacial drift of the Pleistocene period, which covers almost every part of the state, can not be looked upon as a possibility, for not only have the glacial deposits never been known to produce, but their very nature seems to preclude the probability of their doing so. It is true that small quantities of gas have been found in the drift of this and other states, but as will be shown later, these occurrences can not be expected to be of any importance.

GEOLOGICAL STRUCTURE IN IOWA.

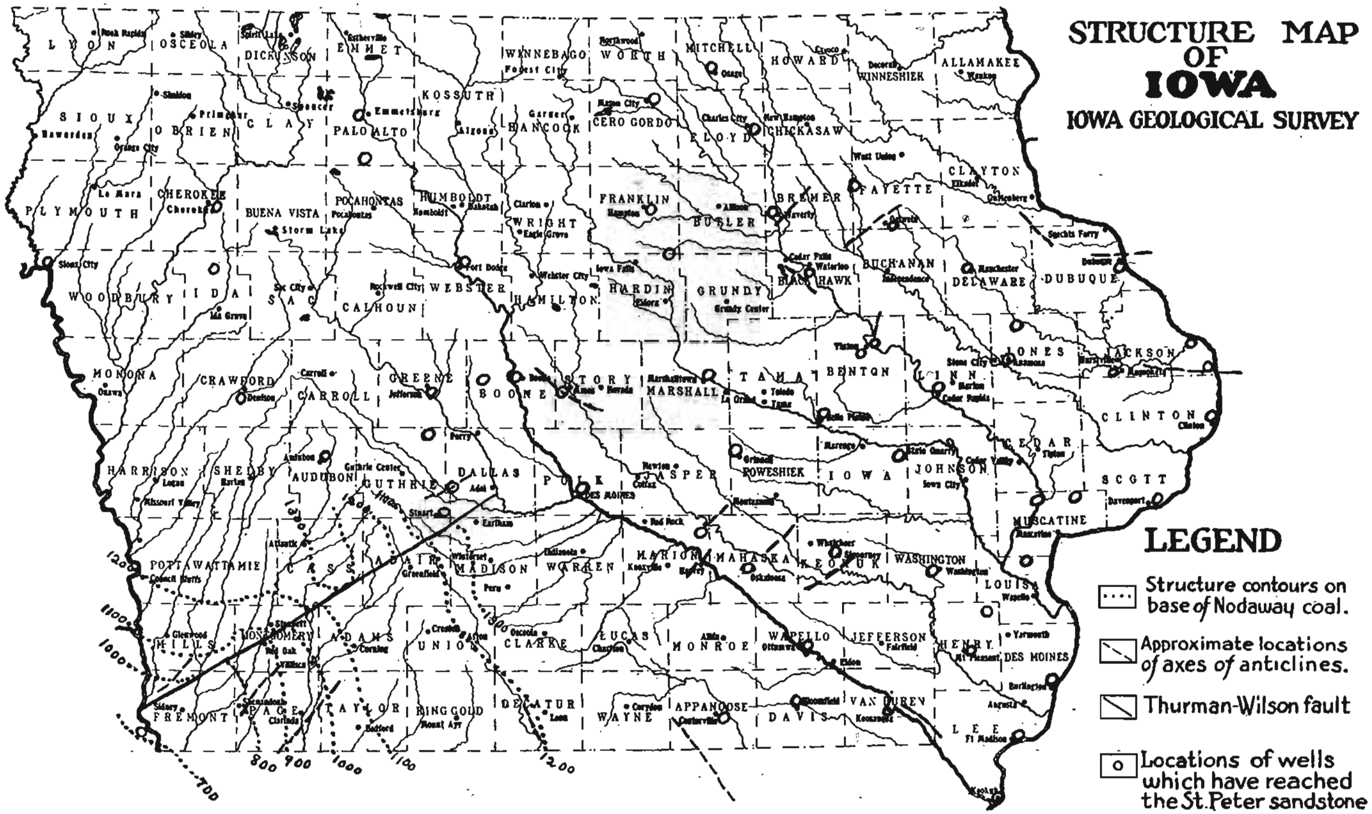
The regional structure of Iowa is extremely simple. The rocks dip from the northeast to the southwest at a rate which varies between twenty feet per mile in the eastern part of the state and six feet per mile in the southwestern part. Iowa may be considered as lying on the north flank of the great prairie geosyncline, whose trough is in western Kansas and Nebraska. There is but one structural feature which has produced an important variation from the general monoclinal structure. This is the Thurman-Wilson fault, a dislocation of small magnitude which extends from the southwest corner of the state northeastward into Dallas county. The effect of this fault is most noticeable when one considers the areal distribution of the Pennsylvanian rocks[4]. Modifying the general monocline are numerous minor folds, and these are of particular interest to the geologist who is in search of oil, for it is beneath such minor folds that oil accumulates if it be present in the region. Owing to the thick mantle of drift which covers the state, it is very difficult to find these subordinate folds, and undoubtedly there are many of which nothing is known. Furthermore little effort has been made in Iowa to locate such deformations. However, on the accompanying map (Plate IV) are shown the locations of all such folds as are known to the Survey. Many of these are of ample size to have caused an accumulation of oil and gas provided the other necessary conditions exist.

In many parts of the state, notably in Cerro Gordo, Decatur, Floyd and certain of the southwestern counties there are numerous local faults and steep dips. Many of these can be definitely shown to be due to the thickening and thinning of the strata and to inequalities of deposition, and have no significance in determining the true structure.

In a later paragraph (page 38) certain of these small folds will be discussed in greater detail, as favorable locations to be tested.

Metamorphism of Iowa Rocks.—As has been shown previously, the rocks in Iowa have not been subjected to any noteworthy folding. Little metamorphism of the extreme type has taken place, and the only changes in the rocks since their deposition have been of the nature of cementation. The rocks seem not to have been subjected to any considerable lateral pressure and certainly to no great heat. Metamorphism, therefore, which has taken place, must have resulted from the pressure of overlying rocks and the action of ground water. Yet the carbon ratios of Iowa coals cover a range between 45 and 58, which would seem to indicate that considerable de-

[4]Tilton, Jno. L., Jour. Geol., Vol. XXVII, 1919; see also paper by Tilton on the Missouri series, in this volume, also one on the Geology of Cass county in volume XXVII, Iowa Geol. Survey.


STRUCTURE MAP OF IOWA
IOWA GEOLOGICAL SURVEY
LEGEND
Structure contours on base of Nodaway coal.
Approximate locations of axes of anticlines.
Thurman-Wilson fault
Locations of wells which have reached the St. Peter sandstone
LYON
OSCEOLA
DICKINSON
EMMET
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
SIOUX
O BRIEN
CLAY
PALO ALTO
KOSSUTH
HANCOCK
CERO GORDO
FLOYD
CHICKASAW
FAYETTE
CLAYTON
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
BUCHANAN
DELAWARE
DUBUQUE
WOODBURY
IDA
SAC
CALHOUN
WEBSTER
HAMILTON
HARDIN
GRUNDY
BLACK HAWK
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
CLINTON
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
CEDAR
SCOTT
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE
1200
1100
1000
700
800
900
1000
1100
1300
1200

volatilization has occurred. According to White[5] a carbon ratio of 45 to 60 is necessary in order that oil and gas be present in rocks of Iowa. This condition has been fulfilled. However, as has been pointed out previously, the evidence of the carbon ratio in Iowa is not conclusive either for or against the presence of oil.

OCCURRENCES OF OIL AND GAS IN IOWA.

No authentic instance is known of the occurrence of oil in Iowa. For many years small amounts of an inflammable gas have been known to occur in glacial drift in the southeastern part of the state. In Louisa county, near Letts, a number of comparatively shallow wells, which penetrated into an old forest bed at the base of the Kansan drift, have produced enough gas to light nearby houses. This gas probably is not a true natural gas of the type which occurs associated with deposits of petroleum. No analyses are available which show the exact nature of the gas, but it is known that the inflammable component is methane. The rock pressure of the gas has been reported[6] as about 9 pounds per square inch, and the flow is small. In Story county a small flow of gas was found ninety feet from the surface, and between two layers of hard rock. Two other tests drilled nearby obtained small amounts of gas under similar conditions. Beyer[7] believes that the reservoir is located at the top of the Pennsylvanian but advances no evidence to disprove the possibility that it originated in the adjoining drift.

At various times oil showings have been reported in different parts of the state, but in nearly all cases investigation has shown that the occurrence can be explained on other than natural grounds. The leakage of refined oil from storage tanks has given rise to most such reports.

A few years ago a small amount of dark colored petroleum was found in a spring in a valley about two miles south of Shannon City. This was examined by Dr. James H. Lees, of the Iowa Geological Survey, but he reported that owing to the

[5] White, David, Jnl. Wash. Acad. Sci., Vol. 6, pp. 189-212. 1915; Bull. Geol. Soc. Amer., Vol. 28, pp. 727-734, 1917.

[6] Ia. Geol. Survey, Vol. XI, p. 124. Proc. Ia. Acad. Sci., Vol. I, Pt. II, pp. 68-70.

[7] Ia. Geol. Survey, Vol. IX, pp. 236-237.

absence of outcrops in the vicinity he was unable to determine the source of the oil. The drift at Shannon City is underlain by rocks of the Missouri series of the Pennsylvanian.

Oil has been reported also from a spring a few miles southeast of Decorah, in Winneshiek county, but the circumstances surrounding this occurrence have tended to cast doubt on its authenticity. A well was drilled nearby on strength of this showing, but found no traces of oil.

Small amounts of bitumen have been found in geodes which are common in the Keokuk beds of the Mississippian, but it is not believed that such occurrences are of more than scientific interest.

At the base of the Galena dolomite in northeast Iowa there is found a thin bed of bituminous shale, known locally as "oil rock". This oil rock is distributed throughout the lead and zinc districts of Illinois, Wisconsin and Iowa, and appears to have had an important influence in the formation of lead and zinc ores. When dry the shale burns rather readily, and with a smoky flame. Examination by the Bureau of Mines shows that the shale owes its inflammable nature to the presence of the remains of Algae. The following analyses illustrate the character of this shale. This rock has been interpreted by

ANALYSIS OF OIL ROCK (Basal Galena), PLATTEVILLE, WISCONSIN.*

	Capitola Mine	Big Jack Mine
Moisture	5.75	8.10
Volatile	22.08	18.65
Fixed Carbon	4.23	3.41
Ash	67.93	69.84

some people as an indication of the presence of oil, and at least one or two tests have been drilled in the vicinity of its outcrop, with negative results. In some other cases it has been penetrated in wells and has been reported as coal. This oil shale will be treated further under the discussion of Ordovician Rocks.

A few miles south of Centerville, and just across the state line in Missouri, some showings of oil have been obtained in rocks of Pennsylvanian age, but no commercial production has resulted.

*Illinois Geol. Survey, Bull. 21, p. 29, 1914.

GROUND WATER IN IOWA.

Ground water is found in considerable amounts in every series of the Iowa section, but the most important water horizons are the sandstones of the Cambrian and Ordovician. Owing to the very gentle southwest dip of the strata, the artesian head is generally low and it is only in the northeastern third of the state that flowing wells are obtained. An exhaustive report on the underground waters of the state will be found in Volume XXI of the Iowa Geological Survey.

In general the mineral content of the Iowa waters is low. The highest content is found in the Mississippian and Pennsylvanian beds, and the lowest in the Cambrian.

The gathering ground of all water-bearing strata is in the northeast corner of Iowa, and in states adjoining. It is therefore to be expected that the mineral content of the waters will be found to be lowest here, and to increase towards the southwest. Norton[8] has shown this to be true.

The movement of ground water in Iowa is from northeast to southwest, or in the direction of dip. The rate probably is slow. The possible effect of this ground water movement is not entirely clear, but it seems probable it may have exercised a "flushing" action, as described by Rick[9] and thus have removed any oil which may have formed in the Iowa rocks. Such a flushing action would depend on a number of factors, chief of which would be the rate of movement, and the continuity of the sands.

However, under nearly similar conditions in eastern Kansas and Oklahoma, flushing has been inoperative and there seems to be no reason for believing that it would be more effective in Iowa, except perhaps in the northeast part of the state, where the uniformly fresh waters of the early Paleozoic strata probably have had such an action. This view is supported by the fact of the increasing mineralization to the southwest.

STRATIGRAPHIC CONSIDERATIONS.

In the following pages each series of rocks in the Iowa section is discussed in detail, its characteristics described, and the possibilities of the occurence of oil and gas indicated.

8Norton, W. H., U. S. Geol. Survey. Water Supply Paper 293.
9Rick, John L., Econ. Geol.

Pre-Cambrian.—The pre-Cambrian rocks of Iowa are quartzite, and intruded greenstone dikes. They offer no hope whatever, of obtaining either gas or oil.

Cambrian.—Small amounts of gas have been found in Cambrian rocks of New York, but at no place has oil been found in rocks of this age. The Iowa Cambrian includes thick sandstones, some sandy shale, and about fifty feet of sandy dolomite. It is almost wholly lacking in organic material which might serve as a source, and could not be expected to act as a reservoir unless through faulting or otherwise, it be brought into contact with younger beds. Cambrian rocks are distinctly unfavorable for prospecting.

Ordovician System.—

Ordovician
- Maquoketa shale
- Galena
  - Galena dolomite
  - oil rock (0 to 15 feet)
- Decorah shale
- Platteville limestone
- St. Peter sandstone
- unconformity.
- Prairie due Chien
  - Shakopee dolomite
  - New Richmond sandstone.
  - Oneota dolomite

The rocks of the Ordovician system in Iowa are chiefly limestones and sandstones with a thick shale member, the Maquoketa, at the top. The various formations are here discussed in order.

Prairie du Chien Formation.—Composed of three members, the Oneota dolomite below, the New Richmond sandstone, and the Shakopee dolomite above. The upper and lower members are porous buff, crystalline dolomites, which generally have a sandy appearance and commonly are reported as sandstones by drillers. The New Richmond member is composed of about twenty feet of hard, light colored quartzitic sandstone.

The Prairie du Chien is relatively unfossiliferous, and no traces of organic matter have been noted in it. The high porosity of the dolomites makes them favorable reservoirs, provided oil be present, but they themselves can not be looked upon as sources of oil or gas. At many points in eastern Iowa the dolomites of the Prairie du Chien carry considerable amounts of artesian water.

St. Peter Formation.—The St. Peter is a massive, uniform, generally rather loosely cemented sandstone. The color is irregular, ranging from white through yellow, brown, and red, according to the amount and stage of oxidation of the iron salts present. Occasional zones are found in which the sand is very firmly cemented, and is almost quartzitic. Fossils are rare, and in Iowa no organic matter is found. Owing to its high porosity and the presence of the impervious Platteville above, the St. Peter would be an ideal reservoir, but any hydrocarbons which it might contain would have to originate elsewhere. And it has been shown that the underlying formations are equally unpromising sources. Oil and gas would therefore have to enter the St. Peter from above.

Throughout the northern and eastern parts of Iowa the St. Peter is an aquifer, and its water is notably pure and of low mineral content.

Platteville Formation.—The lower part of the formation is a calcareous shale, and the upper portion also is shaly. In the middle part is a series of bluish to brown limestone, the entire formation being highly fossiliferous. The Platteville, owing to an abundance of organic remains, might be considered as a possible source of oil and gas. It however, contains no reservoirs, and no hydrocarbons have been found in it.

Decorah Formation.—The Decorah formation is composed of highly fossiliferous soft, greenish shale, with occasional thin layers of argillaceous, nodular limestone. Its thickness in Iowa varies from one foot to thirty-five feet. The organic content is relatively high, but owing to its thinness, it can not be considered a promising source of oil.

Galena Formation.—In most places the Galena is a thick bedded, massive dolomite, buff in color and highly porous. In certain outcrops, however, the dolomitization is incomplete. Fossils occur as casts only, and at the outcrop the only organic matter present is in the "oil rock" at its base. This oil rock is a highly bituminious shale which, on distillation has been found to give off hydrocarbons[10] and which, in its dry state, burns readily. It is rather local in its occurrence, and is best developed in the lead and zinc district of Iowa, Illinois and Wisconsin, where its presence seems to be related to that of the ores. The thickness in Iowa is usually less than fifteen feet.

It seems probable that under the proper conditions the oil rock might give rise to petroleum or gas. The history of the Ordovician rocks of Iowa, however, seems not to have included such events, for wherever the horizon has been studied, either in wells or at the outcrop, the shale remains high in bituminous material. Evidently the forces necessary to effect distillation have not been active. Furthermore, the slight thickness of oil rock present makes it improbable that large amounts of petroleum would result, even were distillation complete. It will be noted that the carbon ratios of the shale are extremely low, indicating that the force lacking is that of regional metamorphism.

Maquoketa Formation.—The uppermost member of the Ordovician series is a thick bed of dark colored shale, with thin layers of shaly limestone. At many horizons the Maquoketa is highly fossiliferous and its dark brown to chocolate color seems to be due in large part to contained organic matter. Wells at Monticello, Anamosa, Grinnell and Mason City have passed through highly bituminous beds in this formation, but have found no signs of oil.

The following analyses of typical Maquoketa shale give a good idea of its character:

	A.	B.	C.	D.
Moisture	.75	1.20	.54	3.58
Volatile	14.12	8.16	8.26	17.59
Fixed Carbon	6.84	2.85	2.85	3.09
Ash	78.29	87.79	83.17	75.74

A. 1 mile east Savannah, Ill. 10 feet below surface.
B. Howleys Mill, Little Maquoketa R. near Channingsville, Ill.
C. Dubuque, Iowa. Shaft near Levines diggings.
J. D. Whitney. Geol. of Iowa. Vol. I, pt. 1, pp. 358-360, 1858.
D. Sec. 36-24N-4E. Near Mt. Carrol, Ill.
Ill. Geol. Survey, Vol. 21, p. 83, 1914.

[10] Ill. Geol. Survey, Vol. 21, p. 29, 1914.

It is believed that the Maquoketa is the source of the oil in the Colmar field in Illinois. The formation in northwest Iowa is 200 feet thick, but thins to the westward, so that wells at Des Moines and Ames encounter much less than this, and at Centerville the Maquoketa is missing.

In the Colmar field of Illinois the Hoing sand, from which the small production is obtained, is a series of non-continuous sand lenses on the eroded surface of the Maquoketa shale. These lenses are irregular in distribution and of limited extent, and it is only where there is a happy combination of favorable structure, underlain by a thick sand, that accumulation has occurred. Many well defined domes in western Illinois have proven unproductive, owing to absence of the sand.

The Maquoketa shale, as shown by the foregoing analyses, affords a large amount of organic material, sufficient to produce a considerable amount of oil and gas. The highest carbon ratio shown here, however, (Sample A) is only 32, while the average of all four is 24.5. According to White's law, oil should not be expected where carbon ratio is less than 45, hence the chances of oil having been formed from the Maquoketa shale in Iowa are not good. No data are available concerning the carbon ratios of the Maquoketa in the Colmar field.

Summary of the Ordovician.—There are four possible sources of oil and gas in the Ordovician rocks—the Platteville formation, the Decorah shale, the "oil rock" of the Galena, and the Maquoketa shale. These in the aggregate, might produce a very large quantity of hydrocarbons. The only possible reservoir is the porous dolomite of the Galena, whose content of $MgCO_3$ seems always to be 40 to 42 per cent, well above the minimum 25 per cent which is necessary in order to provide porosity sufficient to make a reservoir of the dolomites in the eastern fields.

Analyses of the Maquoketa shale and the "oil rock" show them to be high in organic material. The carbon ratio of the Maquoketa ranges from 15 to 32 with an average of 24.5. That of the oil rock averages 15. A ratio of not less than 45 seems to be necessary, hence the rocks of Iowa seem not to have been sufficiently metamorphosed to produce oil or gas.

The Silurian System.—The Silurian system in Iowa includes three dolomite formations, all of which are fossiliferous, but none contain organic material in sufficient amount to be considered as a possible source of oil. Absence of impervious shale beds, either within the formation or above render it improbable that the porous dolomite will act as a reservoir.

The Devonian System.—Of the four recognized Devonian formations two, the Lime Creek and State Quarry beds, are discontinuous, occur only in isolated patches, and lie unconformably on the Cedar Valley formation. They are of no importance in this discussion.

The Wapsipinicon and Cedar Valley formations are prevailingly limestone with some thin beds of shale and a little dolomite.

Devonian rocks are productive of oil and gas in the Appalachian region, but no petroleum has been found in them west of Indiana. The character of the Iowa rocks makes it nearly certain none will be found in the Devonian of this state.

The Mississippian System.—This system has been divided, in Iowa, into four divisions, the Kinderhook, Osage, Meramec and Ste. Genevieve formations. Of these the first is composed of dark shale, sandstone and a subordinate amount of limestone, while the others are predominantly limestones.

The dark colored organic shales of the Kinderhook formation may be considered a possible source of hydrocarbons, and the interbedded sandstone layers offer favorable reservoirs for accumulation. Rocks of Mississippian age produce large quantities of gas and oil in Oklahoma, Northern Texas, Illinois and the Appalachian region. At no place in Iowa, however, have beds of this age been found to be notably bituminous. Some small amounts of pitch have been found in geodes which occur in large numbers in the Keokuk beds near Keokuk, but the occurrence seems to be local.

In the Lawrence field, in Illinois, oil has been found in porous zones of the upper part of the Ste. Genevieve series, but there is at least a possibility that it may have originated in the overlying Pennsylvanian beds.

The sandstone beds of the Kinderhook, where they are covered by younger marine strata, seem to offer some possibilities of producing oil and gas. Some years ago a well was drilled[11] at Redfield in search of oil or gas, and this seems to have thoroughly tested the possibilities of the Kinderhook at that place. The test was located on an anticline, and thus was favorable structurally, but no oil or gas was found. Sands were found in the following depths.

	Depth	Contents
Sand	253 - 293	Artesian water
Sand	388 - 398	Artesian water
Sand	438 - 450	Artesian water
Sand	488 - 498	Heavy flow of mineral water
Sand	616 - 630	Strong flow of water
Sand	823 - 850	Traces of "oil rock"
Sand	868 - 883	Tight sand, water
Sand	960 - 1008	Water sand
Sand	1082 - 1093	Pronounced asphaltum
Sand	1093 - 1100	
Sand	1277 - 1290	Water sand
Sand	1302 - 1341	

The Pennsylvanian System:

The Des Moines Formation.—The lower Pennsylvanian in Iowa has been subdivided into the Cherokee, Henrietta and Pleasanton formations, in all of which the predominant rock is shale, with a large amount of sandstone and a few beds of limestone in the Henrietta and Pleasanton. The Cherokee is the chief coal-bearing horizon of Iowa and contains many workable coal beds, which have been extensively mined in the southcentral part of the state. Like the Des Moines beds of Kansas, Oklahoma and Missouri, the Iowa representatives of the formation contain much organic material.

In the discussion of the origin of oil, it was shown that the conditions under which coal and oil were formed are wholly different. Coal results from carbonization of the plant remains which accumulate in fresh or slightly brackish lagoons adjacent to the coast during periods of critical level, when slight oscillations of the sea level were occurring. Both land and water plants, whose habitat was swamps, are included in the organic material from which coal has been made. So coal may be said to be a near shore or semi-terrestial product. Oil on the other hand, seems to have been formed somewhat farther out on the continental shelf, from more distinctly marine

11U. S. Geol. Survey Water Supply Paper, No. 293, p. 685; Iowa Geol. Survey, Vol. XXI, p. 825.

organic debris, such as would have been deposited with the finer shales.

Hence it is not surprising that formations which bear coal are not often found to contain oil also in the same locality. That is, the presence of coal in rocks of a certain formation is evidence that oil is not present also, in that region, although it may be found elsewhere in the noncoal-bearing beds of the same age.

Thus it has been found that while the Cherokee shale of Iowa, eastern Kansas, Missouri and northeastern Oklahoma, which are near shore or lagoonal deposits, contain no oil and much coal, beds of the same age, but deposited at a greater distance from the oscillating shore line, contain oil but no coal. The great Bartlesville sand of northern Oklahoma, is of Cherokee age, and corresponds stratigraphically to certain coal-bearing horizons of Iowa.

The conclusion, therefore, is that the Des Moines rocks of Iowa, at least in the area of their outcrop, hold out no hope for the prospector for petroleum. Westward from the outcrop the possibilities increase, but at no place within the state can the possibilities of Des Moines rocks be said to be attractive. The necessary condition of organic shales with interbedded sandstones is fulfilled, but the presence of coal indicates that oil should not be expected.

The Missouri Formation.—The Missouri formation in southwestern Iowa consists of about 650 feet of alternating shales and limestones, the shales being in places sandy or even grading laterally into sandstones. These beds, following the Kansas usage, have been divided into the Kansas City, Lansing, Douglas, Shawnee, and Wabaunsee stages. The Shawnee and Wabaunsee in Iowa are coal bearing, containing respectively the Nodaway and Quitman coal seams. They may, therefore, be eliminated as possible petroliferous horizons.

The Kansas City, Lansing and Douglas stages include beds which are wholly marine in origin and so far as can now be determined are possible sources of petroleum. Beds of this age are productive in Kansas and northern Oklahoma.

Summary of the Pennsylvanian.—The rocks of the Des Moines formation are regarded as impossible sources of oil and gas, because of the unfavorable conditions under which they were formed. They contain numerous suitable reservoirs.

Beds belonging to the Shawnee and Wabaunsee stages of the Missouri formation may be eliminated for the same reason. Beds of Kansas City, Lansing and Douglas age may possibly be the source of hydrocarbons, but contain few suitable reservoirs. None of these beds, where they can be studied at their outcrops, give any evidence of being petroliferous.

Counties in which these possibly petroliferous beds may prove productive, provided suitable structural conditions exist, include Pottawattamie, Cass, Mills, Fremont, Montgomery, Page, Adams, Taylor, southern Adair, Union, Ringgold and western Decatur.

Permian System.—The Permian is represented in Iowa by about eighty feet of red shales, sandstones and gypsum. These beds appear to have been deposited under arid conditions and offer no inducement whatever to the prospector for oil.

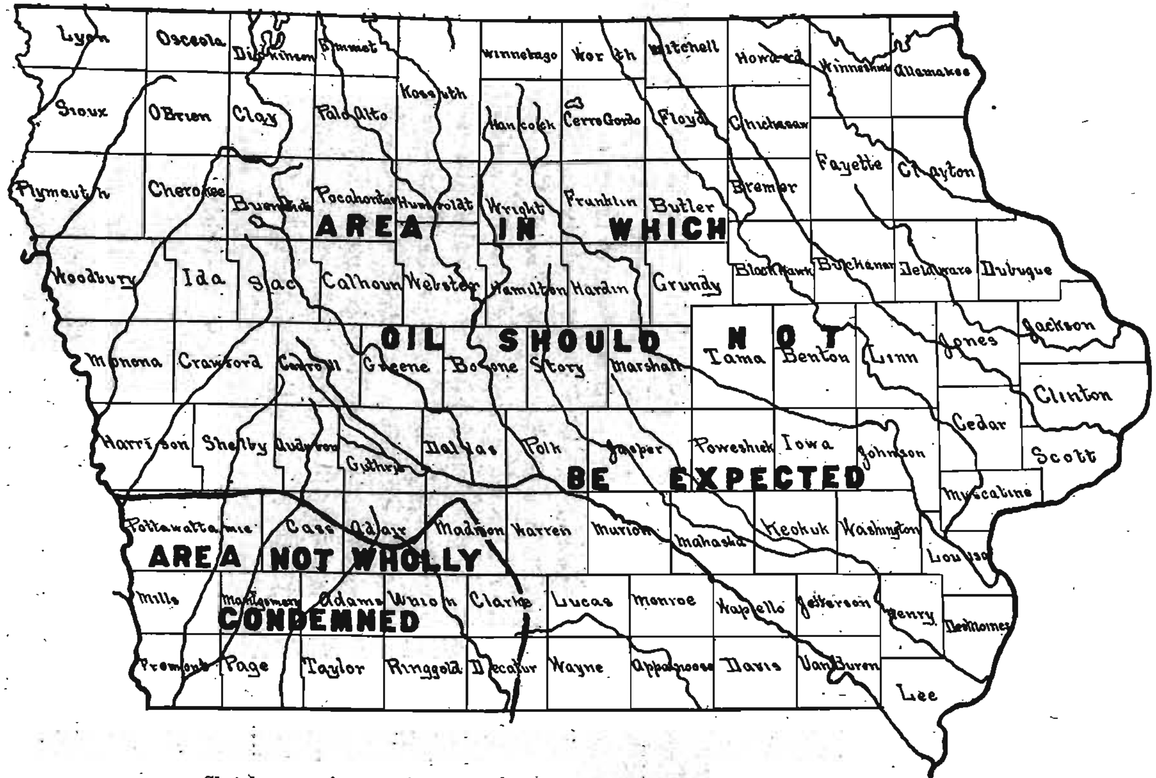
Cretaceous System.—The Cretaceous is represented by sandstones, shales and chalky limestones, which cover a rather large area in western Iowa (see map, Plate III). The series lies unconformably on the older formations below, and is mantled by drift. The Cretaceous terrain is well dissected and study of its outcrops leads to the conclusion that the rocks of this series will prove barren.

The Pleistocene Series.—The Iowa Pleistocene is composed of glacial drift, a terrestrial deposit, formed under conditions that make it certain oil will not be found therein. Small pockets of inflammable gas have been struck in the drift at various places, but these are of small consequence, are of local origin, and their occurrence should not be construed as a favorable indication of oil. These gas pockets will be discovered from time to time during the drilling of water wells, but they can not be located from the surface and are of small value when found. No prospecting should be carried on in glacial drift, for it can lead only to failure.

SUMMARY.

Are Oil and Gas Present in Iowa?

Consideration of the evidence which has been presented in the preceding pages leads to the conclusion that the possibili-



Sketch map of area of Iowa which offers some chance of success.

ties of obtaining commercial production of oil and gas in Iowa are small. In by far the greater part of the state the chances are negligible, and expenditure of money in prospecting these areas should be advised against. In one rather limited area there may be some slight chance for success and while tests in this area are not recommended, it is felt that they may be in some manner justified. These areas are indicated on the map (Plate V).

In the area indicated as being not wholly condemned, tests should reach the St. Peter sandstone, the deepest possible reservoir, at depths less than 3500 feet. Especial care should be taken in testing any sands in the lower two-thirds of the Missouri stage, those of the Kinderhook and the Maquoketa shale. No test should be drilled deeper than the upper part of the St. Peter sandstone.

There are two locations within this general area, drilling on either of which would afford a fair test. An anticline has been reported as extending northwestward from a point about one mile east of Shenandoah in Page county to the northeast part of Township 70 North, Range 38 West. Another elongate fold, which may really be a series of domes, extends from a point four miles west of Braddyville northeastward for some eighteen miles to a point five miles north of New Market. Only the approximate locations of these folds are known, and a more careful examination should be made before a test is begun. If there is no oil beneath these folds, then it is useless to prospect further in southwestern Iowa.

Drilling should be begun only after careful examination by a competent geologist. Unless a test is drilled on a favorable structure the results will not be conclusive.

THE UNFAVORABLE AREAS IN THE STATE

In all parts of Iowa, aside from the southwestern area, drilling should be discouraged for the following reasons:

1. Of the horizons which might be suspected of being productive, the Ordovician has been so well tested that it may well be eliminated from consideration. The St. Peter sandstone has been penetrated by many wells in all parts of the

state (see map, Plate IV), many of them on anticlines, and the results have been negative.

2. Areas of Silurian, Devonian and Cambrian rocks are considered practically hopeless.

3. Areas in which Mississippian and Pennsylvanian beds outcrop are not favorable, as any hydrocarbons present in these rocks can escape.

4. Areas in which the Pennsylvanian series contains coal are not worth testing, except in the deeper horizons.

CONCLUSION.

Iowa contains but one area which, in the writer's judgment, in any degree merits a test for oil. At least two anticlines are known in this area, and a properly drilled well on either of them should show conclusively whether there is oil in Iowa. No other part of the state deserves a test at this time. In the localities indicated a well should be located only after a careful survey by a competent geologist.

It should be emphasized that the chances of failure are very high. The strongest argument in favor of drilling is the fact that few deep wells have been drilled in this part of the state, and hence little is known of the older rocks. There is no direct evidence to indicate that oil will be found. But if citizens of the state insist on drilling within its confines, these seem to be the least unfavorable places in which to operate.

PART II.

OIL AND GAS STOCK PROMOTION

LOSSES BY IOWA PEOPLE IN FRAUDULENT OIL COMPANIES.

It has been estimated that in 1920 the people of Iowa lost nearly $100,000,000 through speculation in wild cat oil stock. This means an average of over $1,000,000 in each county. The losses in the following year probably were smaller, but their total, if it were known, undoubtedly would reach a very respectable figure.

If these losses had been merely a part of the legitimate hazards of the business, little need be said about it, but the fact is that nearly all of this money was worse than wasted, and that from the start the so-called investors had no chance whatever of even securing the return of the principal. Lured by promises of rapid and enormous returns people entrusted their funds to promoters of whom they knew little, and whose schemes they made little effort to investigate. It seems remarkable that men who have had the ability to accumulate a considerable amount of money, and who would never think of buying a farm or a store or a car load of cattle without the most careful investigation, and usually not without expert advice, could so readily be persuaded to invest large sums of money with comparative strangers, and in a business of which they knew nothing. Yet this is what has happened in every county in the state.

It is one of the purposes of this report to point out some of the pitfalls that lie in the path of an investor in oil stocks, and to suggest some means of avoiding them.

WHAT AN OIL COMPANY IS.

An oil company is an organization, usually incorporated, for the purpose of producing, transporting, refining and marketing petroleum. The smaller concerns usually confine their activities to a single one of these departments of the business. The larger companies engage in all of them. Many of the largest companies have comparatively small capitalization, while many very small companies are heavily over-capitalized.

Let us take for example the operation of a large company such as those of the Standard group. Such companies own oil and gas leases on lands which they believe will be productive. On these leases they drill wells, some of which will produce oil, some gas, and others nothing. The oil must be raised to the surface, unless it flows naturally, placed in tanks from which it can be pumped into the pipe lines, and through them conveyed to the refinery, which may be located a few miles or several hundred miles from the wells. At the refinery the oil is passed through stills where, by applications of heat it is broken up into various fractions which are known as gasoline, kerosene, lubricating oil, fuel oil, paraffine, tar, etc. These products must be sold either to the jobber or direct to the consumer. It will be seen therefore, that an oil business embraces the elements of prospecting, mining, transporting, manufacturing and selling and that in order to obtain the maximum of profit a company should carry on all of these. To do so however, requires very large capital, and the majority of small companies find it possible to engage in only one of these elements. Most of the small companies are engaged either in the production of crude oil or in refining. By far the larger number of fraudulent promotions have been by companies of the former class.

The profits obtained in the oil business have been enormously exaggerated. While it is true that many companies have been fortunate in making returns of several hundred per cent on their investments, it is known that the oil business as a whole has made no such profits. The losses resulting from the drilling of dry holes, and purchasing, at high prices, leases which never prove productive, are very effective in keeping down the margin of profit. A dry hole undoubtedly is the most useless thing in the world, and unsuccessful tests costing as much as $200,000 are extremely numerous.

THE OIL BUSINESS.

The business of producing oil, and that of mining, represent the greatest hazards of any legitimate enterprises. The expenses of operation usually leave their returns negligible. Efficiently managed oil companies attempt to remove, as far as possible, the hazards of the business, but there are many of them which are inherent, and which can not be gotten rid of. The best safeguard is that of a scattering of risks, and this, of course, is difficult for a small company. Statistics covering long periods of years show that only 80 per cent of all wells drilled are productive, and this includes the wells in proven fields. Not over 5 per cent of wild cat wells ever prove productive. From this it can be seen that if one drills but a single well he stands an excellent chance of losing that which he has put into it, while if he should drill ten wells, his chances would be greatly improved. In the operation of large companies it is expected that a certain percentage of all wells drilled will be dry, but that the profits on the productive wells will more than balance the losses on the dry ones.

There are numerous instances in which individuals or companies have drilled as many as fifteen or twenty dry holes before getting a productive well. An average well in the Mid-Continent field costs $20,000. It is necessary then before embarking in the oil business to be prepared if necessary, to take considerable loss before any profit may accrue.

Another important safeguard is the use of the best brains and of the best technical advice in the conduct of the business. For instance, if one merely goes out and drills a wild cat well at random his chances of getting oil will be about one in a hundred, whereas if he drills on the basis of good geological advice, his chances are increased to about one in four. It is not putting it too strongly to say that a concern which insists upon carrying on its operations by rule of the thumb is due to fail sooner or later unless it has extremely large resources to draw upon, so that it can afford to play the law of averages. But it is an expensive operation, if one must drill one hundred dry holes in order to get one producing well.

It is the function of the geologist to indicate those places where the chances of obtaining oil and gas are best, to advise against drilling in places where the chances are poor and to remove, so far as possible, the hazards of the dry hole.

The Purchase of Stocks in Promotion Companies.—There is but one safe rule in the purchasing of stock in oil companies; that is to buy only stock in going companies, those which have been and are making money, although not necessarily paying dividends. In the case of new companies which have no dividend record, and have as yet no production, but which are organized solely for the purpose of prospecting there is no such rule that can be applied. Investment in such a company is speculation, pure and simple, and in just the same degree as the wagering of a sum of money on the turn of a card. If however, one wishes to speculate in this way his first consideration should be the character of the men who compose the organization, whether they are first, honest, and second, experienced and competent. A man whose honesty is unquestioned and whose ability to successfully operate a bank is known, may well prove a tragic failure in a business he does not understand. If the officers of a company are dishonest, their competence is not important, for the enterprise probably is due to fail regardless.

The tremendous increase in the use of petroleum and its products in the past decade, with the resultant expansion in the oil industry, has given rise to a veritable flood of stock promotions, many of which, of course, have been legitimate, but the vast majority of which have been only fraudulent. The market for such promotion stock seems to have been unlimited. It is a comparatively simple matter to distinguish an honest promotion from a dishonest one. The advertising methods of the fradulent promoter are in most cases stereotyped. They are highly sensational and extreme. His circulars and advertisements are printed in huge type, and he does not scorn the use of red ink to attract attention. All of his leases are "located in close proximity to great gusher wells," or at least they are located between important fields. He seldom admits a probability of failure. The prospects of success are the only ones he mentions.

Below are listed a number of the advertising devices which are favored by these promoters. The presence in any circulars or advertisements of one or more of these devices should lead the investor to be extremely suspicious.

1. Gaudy circulars printed in large type, and often in

colored ink. A legitimate proposition does not require such advertising.

2. Pictures of large wells (on someone else's lease) and photographs showing the intensive development in well known fields. Such illustrations usually have no relation to the property discussed, and are inserted wholly for psychological effect.

3. Photographs and lists of men such as Rockefeller, Sinclair and other less well known persons who have made fortunes in oil.

4. Lists of small companies which, with an investment of a few hundreds or thousands of dollars, have paid millions in dividends. Such instances undoubtedly are true, but they have no importance unless there be listed with them the enormously greater number of companies of equal size which have never returned even the principal.

5. Computation of the profits to be made "if the well comes in". When one considers the hazards which have been mentioned previously, the folly of such statements is apparent.

6. The offering of "ground floor" opportunity. If there is such a thing as a "ground floor" opportunity, one may rest assured that the promoter himself will take care of it.

7. Map showing the location of the company's property, and directing attention to its proximity to highly productive wells. Mere proximity to a producing well means little. A common occurrence in a producing district is that of a dry hole only a few hundred feet from a large well. Every oil field has its limits, and there is always a last well on each side. The lease shown may be only a quarter of a mile from a producing well, yet if this well be on the edge of the field, the lease is worthless.

8. Statement that after a certain date the price of the stock will be advanced. This is an almost infallible indication of fraudulent promotion.

9. The offer of immediate dividends.

10. The offer of stock at or below par value, and agreement to pay dividends. Any dividend paying stock is sold above par value.

11. Urging the reader to wire for stock before the well comes in. This also is an almost infallible warning.

12. Geological reports. Most present day promoters realize the weight that attaches to a geological report, and their advertising usually includes several such reports. If these reports are couched in terms that are not readily understood by the ordinary reader, they should be viewed with suspicion. There are many pseudo geologists at large who, for a consideration, will write any sort of report desired. They cover their lack of knowledge of the science by an almost ludicrous profusion of technical terms which are designed to confuse or impress the reader. Such a report usually contains glowing promises of gusher wells, and predicts that the property discussed will prove to be one of the greatest producers in the field. A report of this kind is a positive guarantee that its writer is not only incompetent, but probably is dishonest as well. A report by a well trained and honest geologist should readily be understood by any intelligent person.

What Constitutes an Honest Geological Report.—1. It is conservative. There are no glittering promises. The geologist contents himself with the statement of the facts, from which he draws conservative conclusions.

2. It is written in simple language. It can be readily understood. There is usually a minimum of unfamiliar and technical words.

3. It generally includes a structural map (see figs. 2. 3.). On this map there is presented information which makes it possible for another geologist to readily check the work of the first.

4. The standing and reputation of the geologist is as important as that of a lawyer or physician, and it is not more difficult to ascertain. The simplest way to learn whether or not a geologist is reliable is to write to the state geologist at the capitol of the state in which the company operates. Most reputable geologists are members of the national geological societies and a letter to the secretary of any of these societies will bring the desired information. The American Association of Petroleum Geologists maintains an extensive file of information pertaining to all geologists who are engaged in oil

work, whether they be members or not. No geologist whose standing is doubtful can obtain membership in this organization. Dr. Chas. E. Decker, Secretary, may be addressed at Norman, Oklahoma, and will be glad to furnish such information as may be desired regarding any member of the profession. He will not, however, recommend a geologist, but will simply report regarding his training and his standing.

Stock Selling Methods.—While a large part of the promotion stock is sold through newspapers and mail advertising, more of it is sold through agents. By this means the promoter avoids possible trouble with the Post Office authorities. Agents as a rule receive commissions of from 20 per cent to 35 per cent, so that from one-fifth to one-third of the investment is lost immediately the stock is taken. If the remaining operations of the company are conducted on the same lavish basis, it can readily be seen that not much will remain for development. It is estimated that not to exceed 15 per cent of the money paid in for wild cat oil stock ever is used for actual development purposes.

A favorite device of the stock salesman in preparing for a campaign in a county, is to sell or even give to certain prominent citizens, a few shares of his stock. Well known merchants and bankers are the best persons with whom to "plant stock." On this stock immediate dividends are paid for several months. When the salesman again returns and opens his real campaign his prospects are referred to the well known men who already hold stock, and from them they learn that dividends have been paid promptly according to promise. In many cases the merchant or banker may feel so well satisfied with his investment that he becomes an active aid to the salesman. All the usual advertising methods are used, and an intensive selling campaign begins. Particular attention is paid to persons who are known to have some ready money. For instance, the salesman may learn that a certain man has sold a farm or has sold a lot of cattle; or he turns his attention to some widow who has received a considerable amount of insurance. To these persons, particularly if they be individuals who are unaccustomed to making investments, he presents his glittering argument; he points out the advantages of an investment in oil stocks with a certainty of perhaps 12 per cent annually, and the possibilities of truly enormous returns, as compared with the meager 4 per cent or 5 per cent to be obtained from the savings bank or mortgage. It is often the business men with whom he has placed his earlier stock, who are unintentional aids in his campaign.

As soon as the community has absorbed all of the stock that the salesman feels it will take, he disappears. The dividends may continue for a few months, after which they too disappear. There being no assets to speak of, and no production, it is obvious that the dividends paid have not been from earnings, but from income from the sale of stock. This of course can not go on indefinitely.

As a rule the investor has no recourse, for the assets of the company usually include little except office furniture. The money he has paid in to them has been dissipated in the form of commissions, advertising expenses, large salaries and dividends. His only return has been a few beautifully engraved stock certificates, and a liberal amount of experience which, unfortunately, he is all too prone to forget when the next stock salesman comes around.

HOW TO DETERMINE THE VALUE OF AN OIL STOCK.

1. The assets of the company. Before purchasing a store almost anyone would first inquire as to the value of the stock and fixtures. The same rule should apply in purchasing oil stock. An oil company's assets may include: (a) Producing leases, (b) Undeveloped leases, (c) Equipment, machinery, etc., (d) Oil in storage, (e) Cash on hand and receivable, (f) Other tangible assets, such as stock in other companies, buildings, office equipment, etc., (g) An oil company does not have "good will", which may be a valuable asset to a mercantile establishment. Its assets are of the tangible variety.

2. Liabilities. (a) Capital stock, (b) Bonds, (c) Accounts payable.

Simple subtraction will show the condition of the company, provided the items listed have been verified. The setting of values on undeveloped leases is a difficult problem. A lease which is not yet producing has only the value which it would bring if sold. Conservative operators usually place a value of $1.00 on all undeveloped leases, for a very large proportion of such property will eventually prove valueless. In order to place a proper valuation on a producing property, it is necessary to have a careful survey made by a competent engineer or geologist. A rough approximation may be made, however, by considering that a lease which is producing one barrel of oil per day is worth from $500.00 to $1,000, and therefore a lease which is producing ten barrels of oil per day is worth from $5,000 to $10,000. The differing values pertain to different fields.

It is suggested, however, in case an individual or group propose to invest a sum of money in an oil company, that they club together and employ a competent geologist, familiar with the field, to investigate and report on the value of the property involved. If the proposition is a legitimate one, there will be no objection. If objection is made, it is evident that something is wrong. It should be emphasized that it is worse than useless for anyone other than an expert to attempt to determine the value of an oil property. No matter how much experience one may have had in the estimation of the value of farms and livestock, he should not attempt to evaluate either developed or undeveloped oil lands.

INVESTMENTS AND SPECULATION.

Let us distinguish clearly between the two terms investment and speculation. An investment is an enterprise in which the principal is as safe from loss as possible, and the returns from which are subordinate to the safety of the principal. In this class are included: savings deposits, bonds and well secured mortgages. The returns from an investment are, as a rule, small. Speculation on the other hand is an enterprise in which large profits may be expected but in which the safety of the principal and the certainty of any profits at all are not assured. Most oil stocks, the stocks of all new untried concerns, fall into the latter class. The profits made may be extremely large, and the enterprise eventually develop into an investment when its standing becomes assured, but the chances for loss, especially at the beginning, are correspondingly large.

THE ORIGIN AND HISTORY OF EXTINCT LAKE CALVIN

BY

WALTER H. SCHOEWE

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CHAPTER I.

INTRODUCTION.

Problem stated.—The unusual width of the valley of Cedar river, together with the regular and distinct line of bluffs between West Liberty and Columbus Junction suggested to Calvin as early as 1874[1] the possibility of the existence of a former glacial lake in the region. Udden, some years later, in 1899, while working on the geology of Muscatine county, arrived at the same conclusions, mapped the ancient shore lines, wrote a description of the lake site and named the old "fossil" lake, 'Lake Calvin,'[2] in honor of its discoverer, Dr. Samuel Calvin, then director of the Iowa Geological Survey. Since Udden's work, however, was confined to Muscatine county, the entire site of the extinct lake had never been mapped and described. Furthermore, conclusive evidence of Lake Calvin's existence had not been presented and a discussion of the inlet and outlet of the lake were wanting entirely. Progress in Pleistocene geology, especially in the recent interpretation of the gumbotil[3] and the development of the theory of its origin, also demanded a reconsideration of the lake problem. With these considerations in mind, the writer undertook the necessary work, the results of which are incorporated in this report. The problem of the writer's investigations thus resolved itself into the following points:

1. to establish without a doubt either the existence or non-existence of Lake Calvin,
2. to carefully map and describe the exact and complete extent of the ancient lake, if such existed,
3. to account for the lake's origin and to trace out fully the lake's history if there was a lake,

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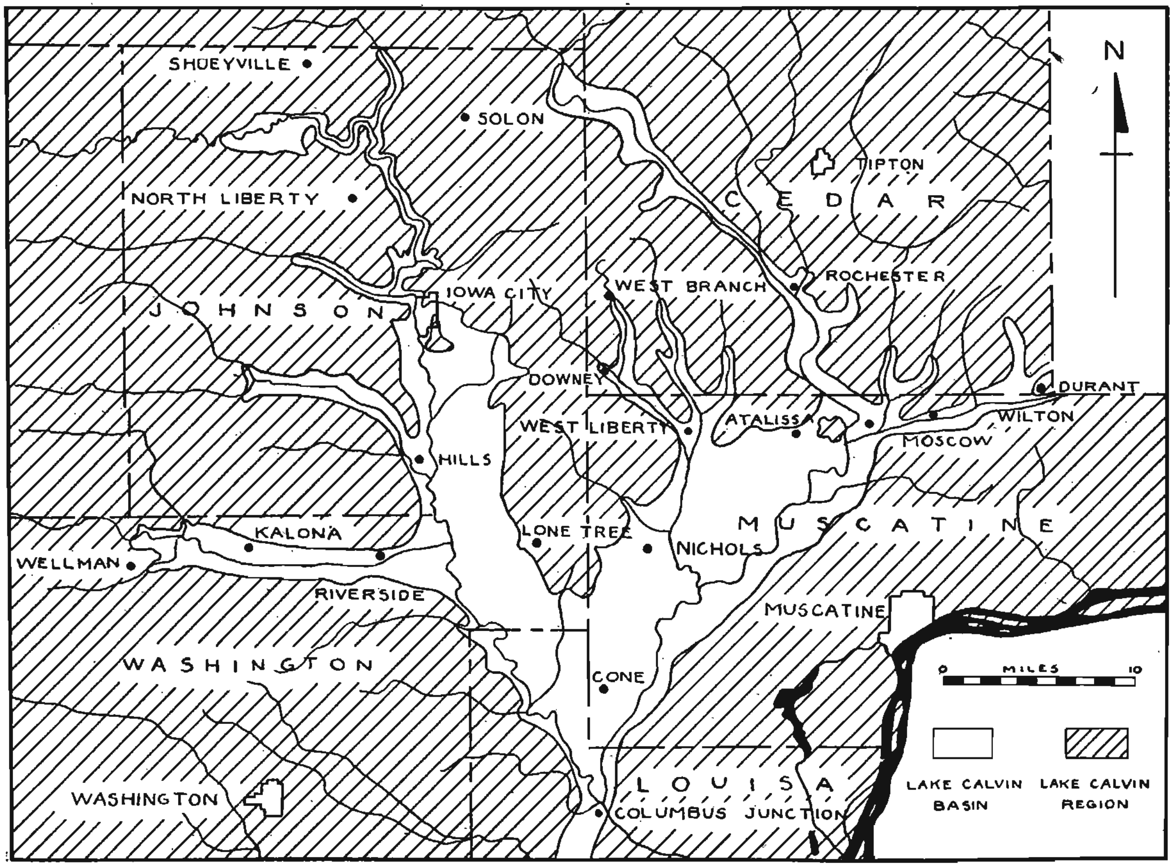
1 Calvin's report to President Thatcher of the State University of Iowa, 1874. Partly reprinted in Udden's report on the "Geology of Muscatine County": Iowa Geological Survey, Vol. IX, pp. 352 and 353, 1899.

2 Udden, J. A., Geology of Muscatine County: Iowa Geological Survey, Vol. IX, p. 357, 1899.

3 Kay, George F., Gumbotil, a New Term in Pleistocene Geology: Science, New Series, Vol. XLIV, Nov. 3, 1916. Reprinted in Iowa Geol. Survey, Vol. XXVI, pp. 217 and 218 1915.



Map showing the location and extent of extinct Lake Calvin.

4. to test the gumbotil hypothesis by seeing whether the presence of a Lake Calvin was in harmony with or detrimental to the gumbotil idea.

Location of extinct Lake Calvin.—Geographically, extinct Lake Calvin lies in the southeastern part of Iowa. The site of this former expense of water, as can be seen from Plate VI, is confined chiefly to an area lying roughly parallel to Iowa and Cedar rivers, from Iowa City and Moscow in Johnson and Muscatine counties respectively, in the north, to Columbus Junction, Louisa county, in the south. Physiographically, the area under discussion is a distinct unit, being bounded on the east by the Illinoian plain and on the north, west and south by the Kansan uplands.

Lake Calvin Basin Defined.—The Lake Calvin basin is limited to that area which was actually the site of the former glacial body of water as compared to the surrounding region which it was necessary to consider for a complete and a clearer understanding of the problem. The latter is termed the Lake Calvin region. The relation between the two is made clear by referring to Plate VI. It is the intention of the writer to confine his theme, as much as possible, to the Lake Calvin basin.

General Characteristics of the Basin.

Topography and relief.—The Lake Calvin basin is an extensive lowland surrounded on all sides by drift uplands rising above it to the height of eighty to one hundred feet. Having been the site of a former lake, its topography is more or less that of a monotonous plain with but little relief. This flat

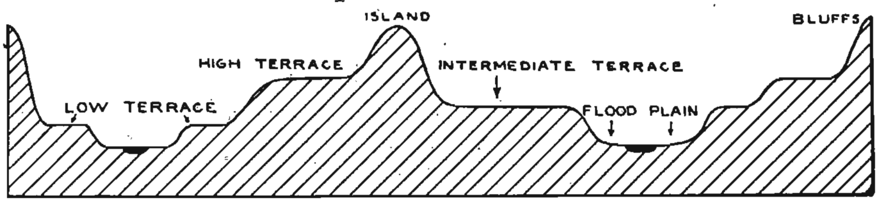


FIG. 6.—Generalized cross-section of the Lake Calvin basin.

stretch of country has an elevation of about 680 feet above sea level in the northern extremity and slopes gently southward at a rate of two and one-half to three feet per mile for a distance of about twenty-five miles, where it has an elevation of 620 feet. The surface of this level plain, however, is not without some relief as a cross section of the region shows. (Figure 6.)

Geology.—Deeply buried beneath the unconsolidated Pleistocene sands, clays and tills are the indurated strata of limestone, dolomite, sandstone and shale belonging to the Silurian, Devonian, Mississippian and Pennsylvanian systems. Exposures of bedrock are lacking in the lake basin proper with the exception of some in the valley walls of Iowa and Cedar rivers north of Iowa City and Moscow respectively, and in the arm-like extension of the lake along English river in Washington county.

Drainage in the lake basin.—The Lake Calvin basin lies in the drainage systems of Iowa and Cedar rivers, which empty into Mississippi river a little northeast of the village of Oakville, Louisa county. Old Mans creek, English river, Whiskey Run, Davis and Goose creeks may be mentioned as the most important tributaries of Iowa river, while Wapsinonoc and Mud creeks form the chief affluents of the Cedar. On the whole, the natural drainage of the lake basin is very incomplete. The courses of the master streams, especially that of Cedar river, are marked by various sloughs, abandoned channels, marshes and crescentic ponds.

Culture in the lake basin.—As might be expected, the Lake Calvin basin is primarily an agricultural district in which corn is the most important crop raised.[4] Because of the sandy soil in the vicinity of Moscow and Conesville, the raising of watermelons and cantaloupes has developed as a specialized truck farming industry. Each year several hundred carloads of melons are shipped from these places. Next to truck gardening and the raising of ordinary crops, the raising and feeding of beef cattle and hogs is important. West Liberty, Wilton and Nichols have become the centers for the raising of pure bred hogs. Dairying is slowly developing with headquarters at West Liberty and Wilton. The only manufacturing of any importance is done at Iowa City where several factories have been established. In connection with the cattle raising indus-

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4 U. S. Department of Agriculture, Soil Survey of Muscatine County, Iowa, pp. 9-22, 1916.

try, shipping is extensively carried on. No small village is without its small white stock yard.

With the exception of the numerous good roads in the region, the Chicago, Rock Island and Pacific railway forms the main means of communication between the numerous towns and villages. The main line of the Rock Island system traverses the region in an east-west direction and passes through the towns of Durant, Wilton, Moscow, Atalissa, West Liberty and Iowa City. A north-south line of this same system connects West Liberty and Nichols, Conesville and Columbus Junction. A sub-line extends south from Iowa City with a western branch to Riverside and Kalona and an eastern one to Lone Tree, Nichols and Muscatine. Still another spur connects Wilton and Muscatine.

The largest city on or at the border of the lake basin is Iowa City with a population of about 12,000 inhabitants. Manufacturing is carried on to some extent, but the city is noted for its being the seat of the State University of Iowa and the county seat for Johnson county. West Liberty, Columbus Junction and Wilton are of about 1,500 and 1,000 people and are chiefly commercial and residential towns. Towns of lesser importance are: Durant, Nichols, Riverside, Kalona, Conesville, Atalissa, Hills and Gladwin. In addition, numerous small trading centers are scattered over the region.

Field work.—Field work was conducted during the summer months of 1916 and 1917. Mapping of the lake formed the major part of the work during the first season, whereas the season of 1917 was devoted chiefly to the examination of cuts, the description of sections, the tracing of the temporary Illinoian Mississippi river channel, the studying of the inlet and outlet of the lake, and a careful inspection of the Illinoian drift and topography. A considerable amount of mapping and detailed work in the vicinity of Iowa City was done in the early spring of 1917. Whereas the work of the first field season was accomplished alone and on foot, the second was done largely with the aid of an automobile. During the month of June, 1917, the writer spent four days in the field with Dr. George F. Kay, studying the Illinoian drift, the peat and gumbotil deposits of Louisa county. A day was spent with Professor A. C. Trowbridge examining the outlet of the lake in the vicinity of Columbus Junction. During the month of August, 1917, the writer was accompanied in the field by Mr. Bert C. Gose of Simpson College. In addition, several local excursions and week-end trips were made during the fall of 1917 and the month of June, 1919, completing the necessary field work.

Although Lake Calvin lies almost entirely in Muscatine and Johnson counties, field work was not restricted to that area, but included to some extent the whole region in Iowa affected by the Illinoian ice sheet, which includes practically the entire southern half of eastern Iowa, or the following counties: Lee, Des Moines, Louisa, Jefferson, Henry, Muscatine, Washington, Johnson, Cedar, Scott, Clinton and Jackson.

Acknowledgments.—In connection with the field investigation of this problem, the writer wishes to express his appreciation to Dr. George F. Kay, Director of the Iowa Geological Survey, and to Professor A. C. Trowbridge, of the Geological Department of the State University of Iowa, for their field conferences. The writer also acknowledges his indebtedness to Professor Trowbridge for the supervision of the field work and for the examination and criticism of the manuscript. Thanks are due also to the other members of the Geological staff of the State University of Iowa for encouragement and for their keen interest in the problem. The writer also wishes to express his obligation to Dr. James H. Lees, Assistant State Geologist, for editing the manuscript of this report. Finally, great obligations are due to the Graduate college of the State University of Iowa for the granting of a fund of $100 for field research purposes.

CHAPTER II.

HISTORY OF PLEISTOCENE INVESTIGATIONS IN THE LAKE CALVIN REGION.

Although the history of Pleistocene investigation in the Lake Calvin region can be traced back as far as 1852 at the time when David Dale Owen published his "Report of a Geological Survey of Wisconsin, Iowa and Minnesota" no great progress had been made until about 1891 when W J McGee's classic report on "The Pleistocene History of Northeastern Iowa" appeared. Previous to this time, practically all of the work was devoted to the study of the indurated rocks, especially with the idea of developing the mineral resources of the state. It is true that Owen,[5] as early as 1849, noticed erratic bowlders scattered here and there over the surface. To explain their origin, he introduced the theory of strong ocean currents coming from the north and carrying floating ice over the land, which at that time was still submerged. This pioneer geologist was more interested in the Carboniferous and other systems than in the drift.

The work of Owen was followed by that of James Hall,[6] first state geologist of Iowa, and his assistants J. D. Whitney and A. H. Worthen. Hall busied himself primarily with the indurated rocks but gave some attention to the drift, which he believed had "been deposited under the influence of somewhat turbulent currents."[7] In Hall's report, Worthen described the geology of Washington county, including in his discussion loess and drift, the latter having been deposited by "Drift agencies."[8]

C. A. White[9] was the first state geologist of Iowa to give any detailed consideration to the Pleistocene. As early as 1858,

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5 Owen, D. D., Report of a Geological Survey of Wisconsin, Iowa and Minnesota, p. 144, 1852. Calvin, S., Proc. Iowa Acad. Science, Vol. V, p. 64, 1897.

6 Hall, James, and Whitney, J. D., Report of the Geol. Survey of the State of Iowa, Vols. I and II, 1858.

7 Idem, Vol. I, Part I.

8 Worthen, A. H., Geology of Iowa, Vol. I, pp. 241 and 248, published in Hall's report cited in 6.

9 White, C. A., Report on the Geological Survey of the State of Iowa, Vols. I and II, 1870.

glacial striae[10] were discovered by him near Burlington although no account of them was published at that time. Later he fully described the glacial deposits and recognized their origin, without, however, separating the various surface drifts into their respective ages. He described briefly the drift of Washington county, but dealt in more detail with the coal found in that and Muscatine counties.[11]

As early as 1887, Calvin[12] attempted to account for the origin of the loess, "the peculiar yellow clay, so well known in rainy weather at least, in the roads and fields near Iowa City."[13] Calvin recognized its connection with the great continental ice sheet and believed then that the loess represented the finest mud that was deposited in a lake. It was his contention that the surface was not all covered with ice but that "lakes of unfrozen water"[14] were hemmed in by ice barriers. It was not until later years that Calvin understood the eolian origin of the loess.

Ice furrows near Iowa City were described by Webster[15] as early as 1888. McGee[16] refers to these glacial scorings as being the only ones occurring in northeastern Iowa. In the same year, Shimek[17] described some of the fossils found in the loess at Iowa City and Witter [18] made some observations on the loess in the vicinity of Muscatine.

It was for W J McGee[19] to differentiate more than one drift sheet in Iowa. His detailed work in northeastern Iowa, which includes practically all of the Lake Calvin region, except that portion in Washington and Louisa counties, led him to believe that there were two distinct drift sheets in Iowa

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10 Keyes, C. R., Glacial Scorings in Iowa, Iowa Geol. Survey, Vol. III, p. 154, 1893.

11 White, C. A., Report on the Geological Survey of the State of Iowa, Vol. I, 1870.

12 Calvin, S., Fragments of Geological History, Johnson County, Iowa Historical Record, 1-3, pp. 100-107, 1885-1887.

13 Idem, p. 106.

14 Idem, p. 106.

15 Webster, C. L., American Naturalist, XXII, pp. 408 and 409, 1888. Keyes, C. R., Glacial Scorings in Iowa: Iowa Geol. Survey, Vol. III, pp. 152 and 153, 1893.

16 McGee, W J, The Pleistocene History of Northeastern Iowa: U. S. Geological Survey, Eleventh Ann. Rept., Pt. I, p. 200, 1891.

17 Shimek, B., Notes on the fossils of the loess at Iowa City: Amer. Geol., Vol. I, p. 149, 1888.

18 Witter, F. M., Some Additional Observations on the Loess in and about Muscatine: Proc. Iowa Acad. Science, Vol. I, Part I, 1888.

19 McGee, W J, The Pleistocene History of Northeastern Iowa: U. S. Geol. Survey, Eleventh Ann. Rept., Pt. I, pp. 189-577, 1891.

separated by a forest bed. Both the "Lower" and the "Upper" till, as McGee named the two drift sheets, are represented in the Lake Calvin region. In addition to describing the two tills, this pioneer geologist also mentioned the terraces along Iowa and Cedar rivers and discussed in some detail the old Goose Lake channel which was occupied by Mississippi river during the Illinoian stage of glaciation. McGee did not confine his work to the Pleistocene deposits, but also included in his studies the indurated strata.

In 1892, Professor Witter[20] of Muscatine published an account of the first gas well in the drift, which was located in the northern part of Louisa county, and in the following year Keyes[21] described the glacial scorings found in the lake region.

In 1894, at the time that Mr. Frank Leverett of the U. S. Geological Survey was working on his newly discovered drift, the Illinoian, Francis M. Fultz[22] of Burlington, independently of Leverett, found evidence of the same younger till sheet in southeastern Iowa. Erratics of a jasper conglomerate were known to exist all the way from eastern Ohio to western Illinois and as far south as Kentucky. The presence of these Huronian erratics seemed to prove that the ice sheet had formerly extended as far south as Kentucky and as far west as Illinois, but at that time the idea that the great ice mass could have crossed the deep valley of the Mississippi and invaded southeastern Iowa seemed incredible. The finding of two of these foreign conglomerates, one by Leverett, and the other by Fultz, in Lee and Des Moines counties, as well as the discovery of terminal moraine deposits, the Sandusky bowlder ridge, in Lee county, were sufficient evidence to those geologists that Iowa had been invaded by an ice sheet from the east. It is interesting to note that at this time the Iowan and Illinoian ice invasions were believed to have been contemporaneous. In 1896 Fultz[23] discovered further evidence of the Illinoian ice incursion by finding gla-

20 Witter, F. M., Gas Wells near Letts: Proc. Iowa Acad. Science, Vol. I, Part II, pp. 68, 69. 1890-1891; Amer. Geol., Vol. IX, p. 319, 1892.

21 Keyes, C. R., Glacial Scorings in Iowa: Iowa Geol. Survey, Vol. III, pp. 152-163, 1893.

22 Fultz, Francis M., Extension of the Illinois Lobe of the Great Ice Sheet into Iowa: Proc. Iowa Acad. Science, Vol. II, pp. 209-212, 1895.

23 Fultz, Francis M., Recent Discoveries of Glacial Scorings in Southeastern Iowa: Proc. Iowa Acad. Science, Vol. III, p. 61, 1896.

cial striae in the southeastern part of the state. In the same year, Bain[24] published his report on the Geology of Washington county. In this report Bain discussed the Kansan drift and the loess and treated in some detail the Washington and other preglacial channels found in that county. An attempt to explain the origin of the drainage system in the county was undertaken also.

McGee's work ushered in a period of detailed investigation regarding problems in the Pleistocene. In-so-far as the region under discussion is concerned, no names are so closely associated with the development of the surface geology as those of Calvin, Leverett and Udden. Calvin's report on the "Geology of Johnson County"[25] appeared in 1897. Calvin, then state geologist, carefully and fully described the Kansan and Iowan drifts of the county and called attention to "the rapidly widening alluvial plain upon which the river," the Iowa river, "enters after emerging from its canyon south of Iowa City."[26] He further directed attention to the fact that "this last plain attains a width of many miles" and finally unites with a "plain of similar character that includes the lower course of the Cedar river."[27] It was not until later that Calvin recognized this "rapidly widening alluvial plain" as the bed of an ancient extinct lake.

Leverett first recognized and separated the Illinoian drift sheet from an older drift covering in southeastern Iowa. Leverett recognized the new drift as early as 1894, but the term 'Illinoian' was not used by him at that time. It was introduced into literature by Chamberlin, then director of the Wisconsin Geological Survey. It appears, however, that Chamberlin credits Leverett with having named the new drift sheet. Leverett is the authority on the Illinoian drift. It was he who mapped and made the most extensive and detailed studies regarding this younger drift. The results of his investigations, covering a period of over ten years, were published in 1899 by the United

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24 Bain, H. F., Geology of Washington County: Iowa Geol. Survey, Vol. V, pp. 113-174, 1896.

25 Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 33-116, 1897.

26 Idem, p. 45.

27 Idem, p. 46.

States Geological Survey as Monograph 38, entitled "The Illinois Glacial Lobe." During the course of Leverett's investigations, numerous articles were published by him regarding observations on the new drift, on the preglacial drainage of the area and on the interglacial intervals. Practically all of these earlier publications are embodied in his final treatise on the Illinoian drift cited above.

In the same year that Leverett's classic monograph appeared, Norton published a report on the "Geology of Scott County."[28] This report deals at length with the preglacial surface of the county and discusses in detail the Cleona channel, a tributary of the preglacial Mississippi river of Leverett. Norton also described the Nebraskan, the Kansan, the Illinoian and the Iowan drifts with their corresponding interglacial deposits.

The most noteworthy and practically the only contribution concerning "Lake Calvin" is that of Udden[29] who was the first geologist to describe and map the old "fossil lake". In his account of the lake, Udden carefully described the old lake bottom in Muscatine county as it was then known, accounted for its origin and named the lake "in conformity with precedents"[30] Lake Calvin, in honor of its discoverer, Dr. Samuel Calvin, then director of the Iowa Geological Survey. It may be mentioned at this point that the borders of this ancient lake have never been mapped except the parts in Muscatine county, although on the "Preliminary Outline Map of the Drift Sheets of Iowa" for 1904, published by the state survey, an extension of this lake appears in Johnson county as far north as Iowa City. In connection with Lake Calvin, Udden[31] and Meyers[32] described some diatomaceous deposits which the writers believed to have some bearing on the existence of the old lake.

Except for a mere mention or two in the publications listed below[33-38] no other description of this ancient body of water has

28 Norton, W. H., Geology of Scott County: Iowa Geol. Survey, Vol. IX, pp. 391-519, 1899.

29 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 246-388, 1899.

30 Idem, p. 357.

31 Udden, J. A., Diatomaceous Earth in Muscatine County: Proc. Iowa Acad. Science, Vol. VI, p. 53, 1899.

32 Meyers, P. C., Report on a Fossil Diatomaceous Deposit in Muscatine County, Iowa: Proc. Iowa Acad. Science, Vol. VI, p. 52, 1899.

33 Calvin's report to President Thatcher of the State University of Iowa, 1874. Partly re-

appeared since Udden's report with the exception of a short account by Calvin[39] in the Iowa State Atlas for 1904, published for the St. Louis Exposition, and a short popular article prepared by the writer[40] for the Iowa Alumnus.

The last two county reports dealing with the geology of part of the Lake Calvin basin were published in 1901. These reports are, "Geology of Louisa County" by Udden[41] and the "Geology of Cedar County" by Norton.[42] As in his other reports, Udden dealt with all the surface deposits, the Nebraskan, the Kansan and the Illionian tills, the loess and the terraces of Iowa and Cedar rivers, and described the old temporary Mississippi river channel of Illinoian time. It is strange to note, however, that although Udden had previously mapped and described Lake Calvin and undoubtedly knew that the old lake had extended into Louisa county, the term 'Lake Calvin' was not used by him in his report. It is true that in discussing the Iowa river lowlands, he mentioned the fact that the northernmost expansion of the lowlands constituted the south end of the West Liberty Plain, but he failed to state the origin of the plain.[43] That writer believed the terraces or the "higher lowlands" along Iowa and Cedar rivers, to have been built up, in part at least, at the time of the Iowan ice invasion.[44] This too, might lead one to suspect that he had perhaps changed his ideas regarding the West Liberty Plain, which he regarded in his Muscatine county report as

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printed in Udden's report on the "Geology of Muscatine County": Iowa Geol. Survey, Vol. IX, pp. 352-353, 1899.

34 Leverett, F., Illinois Glacial Lobe: U. S. Geol. Survey, Monograph XXXVIII, p. 96, 1899.

35 Anderson, Netta C., and Udden, J. A.; A Preliminary List of Fossil Mastodon and Mammoth Remains in Illinois and Iowa, by Netta C. Anderson, and on the Proboscidian fossils of the Pleistocene Deposits in Illinois and Iowa, by John August Udden, Augustana Library Publications, Number Five, pp. 31 and 32, 1905.

36 Norton and Others, Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, pp. 56, 558 and 560, 1912. Also U. S. Geol. Survey, Water Supply Paper No. 293, 1912.

37 U. S. Department of Agriculture, Soil Survey of Muscatine County, Iowa, p. 22, 1916.

38 Alden, Wm. C., and Leighton, M. M., The Iowan Drift, A Review of the evidence of the Iowan Stage of Glaciation: Iowa Geol. Survey, Vol. XXVI, Annual Report for 1915, p. 136, 1917.

39 Calvin, S., Physiography of Iowa: Annual Report of the Iowa Weather and Crop Service for 1902. Reprinted in the Iowa State Atlas of 1904.

40 Schoewe, W. H., Lake Calvin, an Extinct Glacial Lake: Iowa Alumnus, Vol. XVII, No. 4, pp. 193-197, 1920.

41 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, pp. 55-126, 1901.

42 Norton, Wm. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 279-396, 1901.

43 Udden, Op. Cit., p. 61.

44 Op. Cit., p. 113.

being a lake deposit. Futhermore, in connection with his description of the Illinoian drift, Udden mentioned the fact that while the Illinoian ice sheet was building up its terminal moraine, Mississippi river was forced out of its channel and occupied a broad shallow valley which extends from the Iowa river border of the upland, south past Columbus Junction to Winfield and thence west to Skunk river. And then after stating that "The significance of this valley was first made clear by Mr. Leverett,"[45] Udden failed to make clear that this valley was the outlet of his "Lake Calvin" of Muscatine county. Whether Udden changed his views regarding the former existence of the Illinoian glacial lake is not apparent from this report.

Norton described the Kansan drift of Cedar county and outlined in detail the preglacial surface and the preglacial Stanwood channel, probably a tributary of the preglacial Cleona channel. Norton ascribed the terraces along Cedar river to the Iowan ice incursion.

Between 1901 and 1916 but very little, if any, progress along geological lines had been made in the lake district. The few publications[46-49] appended below add nothing new to the Pleistocene knowledge of the region, but deal simply with the already established facts regarding the glacial history of the lake basin.

The only important new contributions of recent date made in reference to the Pleistocene of the region are those of Leighton, then of the Iowa Geological Survey, and Alden of the U. S. Geological Survey. Leighton[50] established the fact that Iowa river north of Iowa City is post-Kansan in age and also that an old preglacial or at least a pre-Kansan valley extended in a northwest-southeast direction across the southern part of Johnson county south of Iowa City. Leighton attributed some of the terraces found along the river to the Iowan stage of glaciation.

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45 Op. cit., p. 109.

46 Calvin, S., Present Phase of the Pleistocene Problem in Iowa: Bull. Geol. Soc. America, Vol. XX, pp. 133-152, 1909.

47 Norton and Others, Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, 1912. Also U. S. Geol. Survey, Water Supply Paper No. 293, 1912.

48 Hay, O. P., The Pleistocene Mammals of Iowa: Iowa Geol. Survey, Vol. XXIII, 1913.

49 U. S. Department of Agriculture, Soil Survey of Muscatine County, Iowa, 1916.

50 Leighton, Morris M., The Pleistocene History of the Iowa River Valley North and West of Iowa City, in Johnson County, Iowa: Iowa Geol. Survey, Vol. XXV, pp. 105-181, 1914.

This same geologist in cooperation with Alden[51] of the U. S. Geological Survey discussed a "gumbo-like" clay found about two miles west of the village of Moscow in Muscatine county. Since the exposure of this "gumbo-like" clay is found so close to the bottom land of Cedar river, the writers did not consider it as being a super-Kansan upland gumbo.[52] These same writers also suggested the possibility that the terraces along Cedar river in the vicinity of Rochester, believed by Norton to be of Iowan age, might "have resulted from slackwater during the Illinoian stage" and that "Such slackwater must have occupied the valley as far up as Ivanhoe bridge southwest of Mount Vernon."[53]

As indicated under "Field Work" on page 59, the writer's field work was not restricted to the Lake Calvin basin, but included practically all the southern half of eastern Iowa. Although it is not the intention of the writer to trace the Pleistocene development of this region, yet it is thought that a word or two ought to be said at this time regarding the preglacial and glacial drainage of the streams, especially in reference to Mississippi river. Probably no other problem in glacial geology is more complex and more difficult to solve than that of the history of Mississippi river during the Quaternary period. It was the displacement of this stream during Illinoian times that gave rise to the formation of Lake Calvin. The most important work in connection with the drainage problem of Mississippi river has been done by; Leverett, McGee, Calvin, Fultz, Warren, Hershey, Udden, Norton, Bain, Keyes, Winchell, Lees, Sardeson, Trowbridge, Westgate, Grant, Claypole, Gordon, Carman and Soper. Although definite conclusions have been reached regarding certain portions of the master stream, yet on the whole, the history of the great river is still uncertain and unsolved. The more important contributions dealing with this complex problem are given in Appendix A.

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51 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift, A Review of the Evidences of the Iowan Stage of Glaciation: Iowa Geol. Survey, Vol. XXVI, Annual Report for 1915, pp. 49-212, 1917.

52 Idem, p. 196.

53 Idem, p. 136.

CHAPTER III.

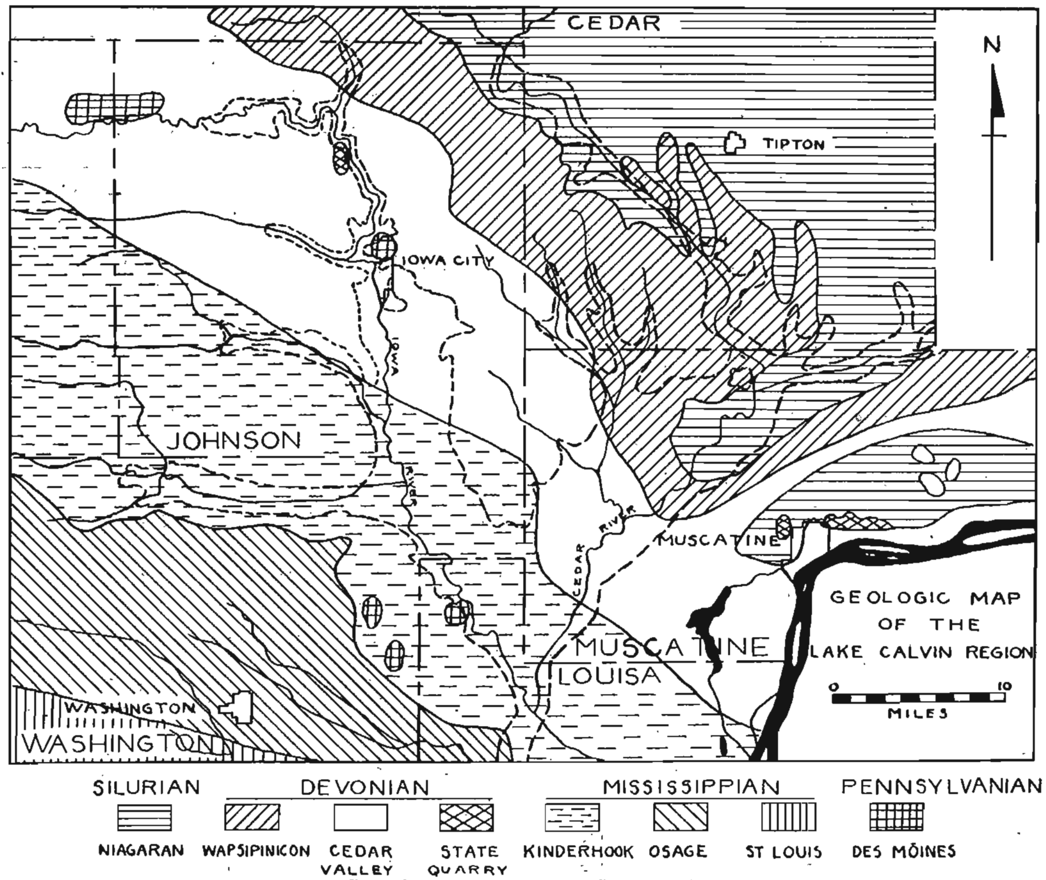
PRE-PLEISTOCENE GEOLOGY AND HISTORY OF THE LAKE CALVIN BASIN.

The Rock Formations.

General Statement.—The bedrock geology of the Lake Calvin basin has been determined mainly from the reports of the various counties in which the old lake lies. Outcrops of the indurated strata are extremely few in number and are practically limited to the northern border and to the English river arm of the lake bed. The rock consists mainly of limestone, dolomite, sandstone and shale and ranges in age from Middle Silurian to Lower Pennsylvanian. The accompanying table is a summarized

TABLE 1. CLASSIFICATION OF THE INDURATED ROCK FORMATIONS REPRESENTED IN THE LAKE CALVIN BASIN.

GROUP	SYSTEM	SERIES	STAGE	SUBSTAGE	ROCK
Paleozoic	Pennsylvanian	Des Moines			Sandstone, shale, coal
	Mississippian	Osage	Burlington	Lower Burlington	Limestone
		Kinderhook		Wassonville	Limestone
				Oölite Ledges	Oölitic limestone
				English River Gritstone	Sandstone
				Maple Mill	Shale
	Devonian	Upper Devonian	State Quarry		Limestone
			Cedar Valley		Limestone
			Upper Wapsipinicon	Upper Davenport	Limestone
			Lower Wapsipinicon	Lower Davenport	Limestone
				Independence	Limestone
				Otis	Limestone
	Silurian	Niagaran	Gower	Anamosa	Dolomite
				Le Claire	Limestone, dolomite



Geologic map of the Lake Calvin region.

classification of the strata of this portion of the state. See also certain other references[54] and Plate VII.

The Silurian System.

THE GOWER LIMESTONE FORMATION.

The Le Claire dolomite member.—The oldest formation of the bedrock in the lake basin is the Gower limestone of Niagaran or Middle Silurian age. This formation, which has been subdivided into the Le Claire and Anamosa dolomite members, attains a maximum thickness of about 120 feet. The Le Claire limestone, about ninety feet thick, is a hard brittle gray or bluish gray rock, in some places oxidized to a buff color. It consists of two phases, a subcrystalline and a crystalline variety. The former phase abounds in moulds and casts of fossils and has a vesicular texture. In many cases it has assumed a brecciated or conglomeratic nature and appears in mounds in which practically all signs of stratification are lost. It is only on the sides and upper surfaces of these mounds that the stratification again is visible. Not only do these beds dip in all directions and at high angles, the higher angles ranging between ten and thirty degrees, but the amount of dip varies considerably in short distances. The crystalline phase of the Gower limestone is pure brittle fine and close-grained dolomite of uniform texture and composition. The rock possesses a subconchoidal fracture and shows close laminations and evenness of bedding. Commonly the layers occur in tilted positions. As it weathers the surface of the Le Claire limestone, especially where it is heavily bedded, becomes deeply pitted with caverns.

The Anamosa dolomite member.—The Anamosa dolomite member has a thickness of thirty feet. It is a light buff, dully lustrous granular rock in which fossils are rare. This soft laminated vesicular dolomite with even and parallel bedding-planes weathers into thin detached laminæ.

Distribution.—The Gower limestone is limited in areal distribution to the northern and northeastern part of the lake bed. As may be seen from the geologic map, Plate VII, a tongue of

54 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 304-329, 1901. Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 268, 1899. Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 54-57, 1897.

this Silurian formation extends down into Muscatine county. Outcrops are found only along Cedar river north of the village of Rochester in the narrow finger-like extension of the lake. The best and most complete section showing both the Le Claire and the Anamosa members is to be seen at the Bealer quarries, located along Cedar river at Cedar Valley. Here about 116 feet of the Gower limestone formation is exposed.

The Devonian System.[55]

Formation and Classification.—The Devonian system is represented in the lake area by the Wapsipinicon, Cedar Valley and State Quarry limestones all of which belong to the upper part of the system. At the present time the Devonian rocks are classified as follows:

CLASSIFICATION OF THE DEVONIAN SYSTEM IN IOWA

	STAGE	SUBSTAGE
Upper	Missing	
	Lime Creek; 97-172 feet State Quarry; 40 feet	
	Cedar Valley; 60-150 feet Upper Wapsipinicon	Upper Davenport; 20-40 feet
	Lower Wapsipinicon	Lower Davenport; 20-35 feet Independence; 20 feet Otis; 10-30 feet
Middle	Missing	
Lower	Missing	

THE WAPSIPINICON FORMATION

Members.—The Wapsipinicon limestone is of such a variable character that it has been divided into the following four members:

Wapsipinicon {
Upper Davenport
Lower Davenport
Independence
Otis

55 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 329-342, 1901. Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 268-303, 1899. Calvin S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 57-79, 1897.

The Otis member.—Lithologically and structurally the Otis limestone varies greatly from place to place. In general it may be described as a pure fine-grained hard, brittle brown to drab rock which breaks with a conchoidal or irregular fracture. The rock in places occurs heavily bedded, especially where it is cracked or fragmental, and in other localities it is thinly laminated. The Otis member, which attains a thickness ranging from ten to thirty feet, is not fossiliferous and contains some flint nodules.

The Independence member.—The Independence member in the lake region is an impure, argillaceous soft buff colored, speckled magnesian limestone which attains a thickness of twenty feet. In places the rock contains angular fragments of other limestones and of silica. At such places, it weathers to an earthy luster while its surfaces become pitted with angular cavities and roughened by protruding particles of sand which are left standing in relief. Locally, the limestone is so argillaceous that it breaks down into clay. This member also contains many siliceous nodules.

The Lower Davenport member.—The Lower Davenport member, often called the Fayette breccia, is an unfossiliferous hard compact, fine-grained whitish limestone which in many places is brecciated. The rock has a conchoidal fracture, is filled with siliceous nodules and in many places occurs in massive beds. Its thickness together with the Upper Davenport member is estimated to range from twenty to forty feet.

The Upper Davenport member.—The Upper Davenport limestone is a thickly bedded, highly fossiliferous, semicrystalline rock, tough and of a gray color. Brachiopod shells are so numerous in some parts of the member that the limestone may be said to be made up partly of coquina layers.

Distribution.—The Wapsipinicon limestone forms the country rock of the region adjacent to Cedar river and occupies a large part of the lake bed in Goshen, Pike and parts of Moscow and Wapsinonoc township. The various members belonging to the Wapsipinicon formation outcrop in the high bluffs along Cedar river from a point one mile north of the village of Moscow to a point about six miles northwest of the village of Rochester.

Other outcrops are found at various places along Sugar and Crooked creeks. In the quarries located on the island-like upland in sections 7 and 8, Moscow township, several feet of the Lower Davenport or Fayette breccia is exposed.

THE CEDAR VALLEY FORMATION.

The Cedar Valley limestone.—The Cedar Valley limestone now considered to be of Upper Devonian age consists of a series of limestones which vary greatly from place to place in color, texture, structure, clay and fossil content. In color the rock varies from a light bluish gray to dark gray, white or yellow. Texturally the limestone is hard, tough, compact and fine grained to soft and somewhat brittle and argillaceous. At places the layers are irregularly bedded, compact, massive and brecciated while elsewhere the strata occur in regular ledges cut by oblique joints. The beds are practically horizontal and yet on close examination of elevations of similar beds at the various quarries along Iowa river near Iowa City, it is seen that the strata have a dip to the south of approximately seventeen feet per mile. Locally, however, the dip may be greater. The rock, on the whole, is very fossiliferous, being filled with the shells of corals and brachiopods, yet there are certain beds in which fossils are rare or absent, especially in those portions which are brecciated. The Cedar Valley limestone is known to have a thickness ranging from sixty to one hundred and fifty feet. However, at no place in this region is its entire thickness exposed. Only fifty feet of this formation can actually be seen in the quarry faces along Iowa river. A typical section in the Cedar Valley limestone is to be seen at the Hutchison quarry located on the west bank of Iowa river just opposite Iowa City. This quarry exposes approximately thirty-two feet of rock in which thirteen distinct beds can be identified. The section is as follows.

HUTCHISON QUARRY SECTION, IOWA CITY

Bed		Feet
13.	Limestone, gray, thinly bedded	3 to 4
12.	Limestone, light gray, brecciated at places	6
11.	Limestone, upper Idiostroma layer	1 1/2
10.	Limestone, gray	1

9.	Limestone, light colored, with numerous *Idiostroma*	1 2/3
8.	Limestone, base of the Idiostroma bed, also birdseye coral	2 1/2
7.	Limestone, hard ledge, gray, with many *Acervularia* and other fossils	2 2/3
6.	Limestone, upper coral reef	2 5/6
5.	Limestone, light colored, few fossils	3
4.	Limestone, hard, bluish gray, separated from No. 5 by three inches of shale	1 1/6
3.	Limestone, bluish	1 1/3
2.	Limestone, hard, fine grained	2 1/3
1.	Limestone, coral reef	1
		31 2/3

Distribution.—The Cedar Valley formation is the bedrock for the southern portion of the Lake Calvin basin and underlies parts of the following townships in Muscatine county: Wapsinonoc, Goshen, Pike, Lake and Cedar, as well as the region bordering Iowa river in Johnson county north of the village of Hills. Practically all of the exposures are confined to the valley walls of Iowa river in Johnson county from Iowa City northward. Two small outliers of the limestones are to be found in the quarries of the small upland area located in sections 7 and 8, Moscow township, Muscatine county, and in the bluff line three-quarters of a mile due east of the village of Atalissa. At the latter locality, the rock is mostly hidden due to slump and overgrowth of vegetation.

THE STATE QUARRY BEDS.

in the lake basin are known as the State Quarry limestone. This formation, with a thickness of forty feet, outcrops in an area three-quarters of a mile by half a mile in extent along the west valley wall of Iowa river in sections 5 and 8, Penn township, Johnson county. The strata consists of a light grayish colored limestone varying in texture somewhat in the different beds. The uppermost layers are filled with the shells of numerous brachiopods, so that this rock may be described as a coquina limestone. The pores and other small openings in the rock are filled with abundant calcite crystals. The middle beds, which furnished the building stone for the Old State Capitol of Iowa, the present Administration building of the State University, are thickbedded, being as much as five feet thick, are well jointed and are highly fossiliferous. Towards the base of the exposures the beds are thinner and range from a few inches to one foot in thickness. Masses of chert bands are distributed irregularly throughout the formation and at places are crowded with imbedded remains of fish teeth. This formation rests unconformably on the Cedar Valley limestones.

The Mississippian System.[56]

Rocks represented.—By far the greater portion of the Lake Calvin basin is underlain by rocks belonging to the basal part of the Mississippian system. These rocks comprise soft greenish shales, fine-grained sandstones and lithographic and oölitic limestones, all of which belong to the Kinderhook and Osage series.

THE KINDERHOOK SERIES.

The Kinderhook series may be divided into four members as follows:

Kinderhook {
- Wassonville limestone
- Oölitic limestone ledge
- English River gritstone
- Maple Mill shale.

The Maple Mill shale member.—This member is a nonfossiliferous greenish gray compact shale with a soapy or greasy luster. Small pale yellow cubes of iron pyrites are distributed throughout the shale. The rock breaks up into small regular rhomboidal blocks. Its thickness is estimated as 180 feet.

The English River gritstone member.—The English River gritstone is a soft fine-grained sandstone made up largely of angular quartz fragments of uniform size and shape. Intercalated with the sandstone are thin seams of shaly material. The bluish gray rock weathers to a dull yellow color. Near the upper part of the member is a thin layer in which the remains of fish teeth are found. Fossils in the form of casts occur, but not very abundantly. Above the sandstone, which has a thickness

[56] Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, p. 79, 1897. Bain, H. Foster, Geology of Washington County: Iowa Geol. Survey, Vol. V, pp. 127-151, 1896. Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, pp. 71-93, 1901.

of ten feet, is a fine, compact grayish nonfossiliferous lithographic limestone from three to four feet thick. This is followed by a nonfossiliferous sandstone very similar in texture and composition to the gritstone below. Its color is soft blue or yellow and it is three feet thick.

The oölitic limestone ledge member.—This rock is a single ledge of white to yellowish limestone which is two or three feet thick and is composed of small spherical oölites imbedded in a matrix of calcareous material. Where it is leached the ledge appears as a porous yellowish rock. Fossils are fairly abundant.

The Wassonville limestone member.—The Wassonville limestone varies from an earthy magnesian to a moderately fine-grained limestone which is more or less arenaceous in places. Toward the base of the member, it occurs normally in thick ledges in which is found a gray chert which locally shows an oölitic structure. The limestone is fossiliferous and is approximately fifteen feet thick.

Distribution.—As indicated elsewhere, the rocks belonging to the basal part of the Mississippian system underlie the major portion of the lake bed basin. From the geologic map, Plate VII, it may be seen that except for a small outlier of Des Moines sandstone located along Iowa river north of Gladwin, Louisa county, the Kinderhook formation forms the country rock of the lake bed in Louisa, Washington and Johnson counties, south of the village of Hills, as well as a small portion of the southwest corner of Muscatine county. The various members of this formation outcrop only along the bluffs of English river westward from about Kalona to Wassonville.

THE OSAGE SERIES.

The Lower Burlington formation.—The Osage series is represented in the region by but one exposure of a buff arenaceous limestone, four inches thick. This lower Burlington limestone outcrops in the old railway quarry located in Washington county, township 77 N., range VIII W., section 16, where it caps about twenty feet of the Kinderhook formation.

The Pennsylvanian System.[57]

THE DES MOINES SERIES.

The Des Moines sandstone.—The Des Moines sandstone of Lower Pennsylvanian age is the youngest indurated rock formation known in the region. The rock occurs as small isolated outliers occupying old pre-Pennsylvanian erosional valleys, 140 feet deep or thereabouts and having a trend S. 30° E. Two of these sandstone outliers outcrop in the lake bed region, one of these being just north of Iowa City, the other north of Gladwin in Louisa county. The rocks belonging to the Des Moines series consist of sandstones interbedded with layers of shale and coal. The sandstone is a light yellowish, thinly bedded, medium-grained, iron cemented rock, rather porous and well jointed. At the Sanders quarry, located just north of Iowa City, where a thickness of twenty-six to thirty feet of the sandstone is exposed the rock is filled with numerous spheroidal limy concretions and with nodules of iron pyrites. The sandstone is interbedded with thin bedded layers of bluish black shales which differ in thickness from several inches to several feet. At places the shale beds are more numerous toward the top of the formation. Layers of coal, one-half inch to a few inches thick, are reported from both localities. In general the Des Moines sandstone and shale lie in horizontal beds. Locally, however, the sandstone and shale, as seen in North and South Sanders creek north of Iowa City, dip at an angle of five degrees in a direction N. 40° E. The formation rests unconformably on the Cedar Valley limestone.

History of the Indurated Rock Formations.

The history of the indurated rock formations or of the pre-Pleistocene geologic history of the Lake Calvin basin is recorded in the belted series of the rock formations which are found crossing the region in more or less roughly parallel bands having a northwest to southeast trend as is shown on Plate VII. This belted arrangement is due to the fact that after the strata had been formed, diastrophism set in, resulting in a slight tilting of the beds in a southwesterly direction.

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57 Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 79-83, 1897. Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 303-317, 1899. Bain, H. Foster, Geology of Washington County: Iowa Geol. Survey, Vol. V, pp. 151-152, 1896. Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. IX, pp. 93-95, 1901.

The oldest rocks outcropping in the area under discussion are exposed along Cedar river and belong to the Gower limestone formation of Middle Silurian age. The history of the region, however, does not commence with these oldest outcropping strata for lying north of the area are found still older rocks of Ordovician and Cambrian times and deep well records[58] reveal the presence of quartzite and slate which are believed to correspond in age to the Sioux quartzite of northwestern Iowa and to the Baraboo quartzite found in south-central Wisconsin, which rocks are considered to be Upper Huronian[59] in age.

The early history of the region seems to be as follows: A vast shallow sea extended over northeastern Iowa in which horizontal beds of sand and clay were deposited. The source of the material probably was the old unsubmerged igneous land mass in northern Wisconsin, Minnesota and Canada. After the sand deposited in this sea was finally converted into sandstone and later changed to quartzite, folding and uplifting occurred, resulting in a tilting of the beds to the southwest at an angle varying from three to seven degrees.[60] From other localities it is known that the newly elevated land surface underwent a long period of erosion, but that finally submergence again set in. The best evidence from well records seems to show that this submergence resulted in a widespread epicontinental sea in which sandstone and smaller amounts of limestone were deposited. The total thickness of these Cambrian deposits is as much as a thousand feet,[61] which indicates a long uninterrupted period of sedimentation.

This period of sandstone formation at last gave way to one during which calcareous and magnesian materials were the chief sediments deposited, for overlying conformably the Jordan sandstone, the upper one hundred feet or so of the Cambrian

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58 Norton, W. H., Underground Water Resources of Iowa: U. S. Geol. Survey, Water Supply Paper 293, Plates X and XI, pp. 293, 375, 447, 1912; Iowa Geol. Survey, Vol. XXI, Plates X and XI, pp. 68, 70, 450, 542, 1912; Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, Vol. III, pp. 196, 197, 199, 1893.

59 Norton, W. H., Underground Water Resources of Iowa: U. S. Geol. Survey, Water Supply Paper 293, pp. 61-63, 374-375, 447 and 449, 1912.

60 Beyer, S. W., Sioux Quartzite and Certain Associated Rocks: Iowa Geol. Survey, Vol. VI, p. 75, 1896.

61 Norton and Others, Underground Water Resources of Iowa, U. S. Geol. Survey, Water Supply Paper 293, p. 63, 1912.

system, rests the Prairie du Chien formation consisting of the Oneota, New Richmond and Shakopee members. After about 250 to 300 feet of these sediments had been deposited, the sea withdrew and a great period of erosion at once set in, resulting in an almost complete removal at several places of the last formed group of strata.[62] The next formation to be laid down was the St. Peter sandstone, which has been believed by many to be of eolian origin,[63] but which now appears to be of marine derivation as pelecypods have recently been discovered in these strata at Minneapolis, Minnesota. The period of sedimentation did not stop with the St. Peter, but continued right on until at least about 400 feet of the Platteville limestone, Decorah shale and Galena dolomite had been laid down. Sedimentation then ceased for a while and erosion was the dominant process in operation. Soon, however, the sea encroached on the land again and the Maquoketa shale, with a thickness of 150 feet, was deposited.

As has been shown by Savage[64] seas covered northeastern Iowa during Silurian time. However, by far the greater part of the Silurian strata found in Iowa and in the region under discussion is of Niagaran or Middle Silurian age. As is indicated elsewhere, the rocks belonging to this age are the oldest strata exposed at the surface in the Lake Calvin basin. These rocks outcrop along Cedar river north of the village of Rochester in Cedar county. In all about 120 feet of Silurian sediments was laid down in the region.

As may be inferred from the typical Silurian section of New York,[65] the Upper Silurian is missing in Iowa and in this region. This fact gives rise to two alternative views: namely, that Iowa was land during Upper Silurian and Lower Devonian times, as seems to be indicated by the unconformity between the rocks of those two ages in northeastern Iowa; or that if the Cayugan, Helderbergian and Oriskanian seas did extend over the region

62 Trowbridge, A. C., The Prairie Du Chien-St. Peter Unconformity in Iowa: Proc. Iowa Acad. Science, Vol. XXIV, pp. 177-182, 1917.

63 Trowbridge, A. C., The Origin of the St. Peter Sandstone: Proc. Iowa Acad. Sci., Vol. XXIV, pp. 171-175, 1917. Sardeson, F. W., Minn. Acad. Nat'l Sci., Vol. IV, pp. 64-87, 1896. U. S. Geol. Survey, Folio No. 201, 1916. Dake, C. L., The Problem of the St. Peter Sandstone: Bull. School of Mines, Univ. Mo., Vol. 6, No. 1, Aug., 1921, pp. 210-216.

64 Savage, Thomas E., Geological Map of Iowa, 1905.

65 Chamberlin and Salisbury, Introductory Geology, p. 388.

those sediments were all removed before the Middle Devonian seas spread out over Iowa.

CLASSIFICATION OF THE NEW YORK AND IOWA SILURIAN

SERIES	NEW YORK	IOWA
Cayugan (Upper Silurian)	Manlius limestone Rondout waterlime Cobleskill limestone Salina beds	
Niagaran (Middle Silurian)	Guelph dolomite Lockport limestone Rochester shale Clinton beds	Gower dolomite Anamosa dolomite Le Claire limestone Hopkinton dolomite
Oswegan (Lower Silurian)	Medina sandstone Oneida conglomerate (and perhaps the Richmond beds)	Waucoma limestone Winston limestone

It is known that the Upper and Lower Silurian seas were restricted, whereas the Middle Silurian sea was widespread in America. This fact indicates also that there were shifting shore lines and that Iowa may well have been land during Upper Silurian times.

Resting unconformably on the Niagaran, thus indicating an erosional interval, lie the Wapsipinicon and Cedar Valley strata of Middle and Upper Devonian age. The rocks of these two formations are mainly limestones and attain a thickness of about 400 feet. The Wapsipinicon and Cedar Valley seas were teeming with life as is now testified by a large number of marine fossils found in the limestone. After about 400 feet of these sediments had been deposited, the sea withdrew and exposed the newly made surface to the elements of weathering and erosion. A long period of erosion seems to have taken place before the sea encroached again upon the land, for the State Quarry beds lie unconformably upon the deeply eroded surface of the Cedar Valley limestone. Conditions for marine life were exceptionally favorable during the State Quarry stage, for many of the State Quarry beds are practically coquina. Not only was the sea inhabited by corals and brachiopods similar to those of the previous seas, but also by thousands of fishes which, due to some unknown cause, suffered a sudden extinction as is now indicated by the fact that the cherty limestone beds of this formation are crowded with their teeth remains. How long this sea remained in the area can not be ascertained; however, suffice it to say that it remained sufficiently long for the deposition of at least forty feet of limestone.

The Devonian seas were followed by the invasion of the Mississippian sea which, judging from the thickness of the Mississippian system of rocks, about 500 feet, covered the region for a considerable length of time. Practically the entire sequence of Mississippian rocks is represented in Iowa, although the oldest formation, the Kinderhook, is the only one of these which aids in forming the bedrock of the Lake Calvin basin. That the Kinderhook sea extended farther north than is shown on the geological map, Plate VII, is shown by the small outliers of what were formerly known as the Sweetland Creek shale in Muscatine county near the city of Muscatine. These Sweetland Creek shales were formerly classified as Devonian on the basis of the fish teeth contained in them, since these are similar to those in the State Quarry beds. The fish whose remains are now found in the Sweetland Cheek shales, however, are now known to have lived in the Kinderhook seas and accordingly the strata are correlated with the Kinderhook. Sedimentation continued for some time, as several of the younger Mississippian formations are known to exist and to outcrop a little south of the southern border of the lake site.

After about 500 feet of sandstone, limestone and shale had been laid down, the sea again withdrew and erosion became active. Erosion seems to have progressed to a rather advanced stage as is indicated by the Iowa City and Louisa county sandstone outliers of Des Moines age, which occupy valleys in the Cedar Valley limestone which had been excavated to a depth of about 140 feet. Thus it appears that the region was deeply dissected before it was submerged beneath the Des Moines sea. It has been generally believed that this last submergence was in the nature of a shallow and restricted body of water occupying valleys rather than covering wide areas. The evidence for this belief seems to lie in the fact that wherever the Des Moines sandstone and shale is found, it is occupying valleys rather than high places. The Des Moines sea undoubtedly oscillated from time to time, as is shown by the interbedding of coal seams of nonmarine origin with the marine sandstone and shale. Finally the sea withdrew entirely and exposed the new surface, which seems never to have been submerged again. Whether younger deposits were laid down is not certain. If so, not only were they eroded away before Pleistocene time, but so also were practically all of the Pennsylvanian formations, excepting the few patches preserved in the valley north of Iowa City and the ones in Louisa and Muscatine counties. These patches of sandstone and shale were preserved because they occupied low places or valleys and hence were thus protected from erosion.

The finding of undoubted Cretaceous fossils[66] in the drift at various places, as at Iowa City, Mount Vernon, Cedar Rapids, Des Moines and Waterloo, has suggested to some the probability that the parent rock from which these fossils have been derived was not very far removed. The finding of a perfect slender belemnite[67] deeply buried in a clay seems to have strengthened the idea that the fossil must have been near to its original home, as it is believed that such a slender specimen could not have sustained transportation for a long distance without being shattered. Udden[68] also described two small deposits in Muscatine county, named the Pine Creek conglomerate, which he states may either belong to the Lafayette formation or be of Cretaceous age. Trowbridge, however, is of the opinion that these deposits are Aftonian.[69] Schuchert,[70] on the other hand, on his excellent maps of North American Paleogeography, does not extend the Cretaceous seas as far eastward as the Lake Calvin basin.

Subglacial Topography.

It matters little whether or not the Mesozoic seas inundated the region here discussed. The fact remains that before the

66 Keyes, Charles R., Eastern Extension of the Cretaceous in Iowa: Proc. Iowa Acad. Science, Vol. I, pt. II, p. 21, 1890, 1891.

67 Norton, W. H., Geology of Linn County: Iowa Geol. Survey, Vol. IV, p. 168, 1894. White, C. A., Geology of Iowa, Vol. I, p. 98, 1870.

68 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 303-316, 1899.

69 Personal Communication.

70 Schuchert, C., Paleogeography of North America: Bull. Geol. Soc. America, Vol. XX, pp. 94 and 95, 1908.

advent of the great continental ice sheets, at least before the Kansan ice invasion, eastern Iowa had been deeply dissected and probably presented a topography quite similar to that found in the famous Driftless Area of southern Wisconsin, and in the adjoining states of Minnesota, Illinois and Iowa.

A study of well records and outcrops of the indurated strata in the lake basin and in the surrounding counties of southeastern Iowa shows that the subglacial topography has a relief of 300 feet or so, and also discloses the presence of numerous large rock-cut channels which probably formed a drainage system of greater magnitude than now exists in the region.

As has been shown by Leighton,[71] Calvin[72] and Thomas[73] the bedrock surface beneath the drift covering in Johnson county has marked irregularities. "Over an irregular area in the central, northern and northeastern parts, and along the the extreme southern border of the county, bedrock is high, but between these two areas there is a northwest-southeast belt in which the bedrock surface is low."[74] The relief of the country was at least over 250 feet, for the highland bedrock surface has an average elevation of about 700 feet above sea level and in the lowland district bedrock is as low as 460 feet above sea level. This northwest-southeast trending lowland with a width of at least eleven miles crosses the Iowa river arm of the Lake Calvin basin south of Iowa City. "The north wall of the buried valley follows more or less closely the boundary between the Devonian and Mississippian formations."[75] This ancient valley undoubtedly extends diagonally across the northern portion of Louisa county and continues along the lowland underlying the Iowa-Cedar river valley of today, until it joins the ancient valley of the Mississippi.

Udden[76] has shown that the subglacial surface under the

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71 Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), pp. 110-112, 1916.

72 Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 48, 90-91, 1897.

73 Thomas, A. O., Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, p. 505, 1912. U. S. Geol. Survey, Water Supply Paper No. 293, p. 420, 1912.

74 Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), p. 111, 1916.

75 Idem, p. 111.

76 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. XI, pp. 326, 327, and plate VII, 1899.

West Liberty Plain (the lowland area bordering Cedar river in Muscatine county) was low and that the valley now occupied by Mud creek lies over a buried valley. The region to the north of the lake bed appears to have been an upland. This ancient valley connected with the one to the south just described. There is a possibility also that the Washington channel[77] may have joined this general lowland area somewhere in the vicinity of Columbus Junction. The Washington channel, to which Bain[78] and Calvin[79] have called attention, extends diagonally across Washington county in a northwest-southeast direction, passing beneath the city of Washington. This ancient buried valley, as well as the one in Poweshiek county at Deep River,[80] may have some connection with the large buried valley underlying the famous Belle Plain artesian[81] basin which extends in a northwest-southeast direction through Tama, southwest Benton and northwest Iowa counties. In the northeast, the West Liberty subglacial lowland was joined by an ancient valley thought by Carman,[82] Norton,[83] Udden[84] and Leverett[85] to be the probable course of a preglacial Mississippi river. It is evident that the present course of Mississippi river between Princeton on the north and Muscatine on the south is of much more recent date than are portions of the river to the north and south of the two mentioned cities.[86] It has been suggested[87] that the preglacial

77 Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, p. 696, 1912; U. S. Geol. Survey, Water Supply Paper No. 293, p. 575, 1912.

78 Bain, H. Foster, Preglacial Elevation of Iowa: Proc. Iowa Acad. Science, Vol. II, p. 23, 1895; Geology of Washington County: Iowa Geol. Survey, Vol. V, pp. 159, 160, and fig. 9, 1896. Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, p. 740, 1912. U. S. Geol. Survey, Water Supply Paper No. 293, p. 611, 1912.

79 Calvin, S., Notes on the Formations passed through in boring the deep well at Washington, Iowa: Amer. Geologist, Vol. I, pp. 28-31, 1888.

80 Bain, H. Foster, Geology of Washington County: Iowa Geol. Survey, Vol. V, p. 160, 1896. Stookey, S. W., Geology of Poweshiek County: Iowa Geol. Survey, Vol. XX, pp. 253, 254, 260, 265, 267, 1909.

81 Mosnat, H. R., Report on the Artesian Wells of the Belle Plain Area: Iowa Geol. Survey, Vol. IX, pp. 530-548, 1899. Stookey, S. W., Geology of Iowa County: Iowa Geol. Survey, Vol. XX, p. 179, 1910. Call, R. E., Iowa Artesian Wells: Iowa Weather and Crop Service, Vol. III, p. 4, March, 1892.

82 Carman, J. Ernest, The Mississippi Valley Between Savanna and Davenport: Illinois Geol. Survey, Bull. 13, pp. 58, 62 and 63, 1909.

83 Norton, W. H., Geology of Scott County: Iowa Geol. Survey, Vol. IX, pp. 413-415, 492-493, 1899.

84 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 327, 1899.

85 Leverett, Frank, The Illinois Glacial Lobe: U. S. Geol. Survey, Monograph XXXVIII, pp. 462-467, 1899.

86 Carmen, J. Ernest, The Mississippi Valley Between Savanna and Davenport: Illinois Geol. Survey, Bull. 13, p. 58, 1909.

87 Carman, Idem, p. 58.

valley of this mighty river extended up the Wapsipinicon river valley to the mouth of Mud creek from which place it extended roughly parallel to Mud creek in a southwest direction as far as Durant. That portion of the channel from the Wapsipinicon river to Durant has been called by Norton the Cleona channel.[88] Although the channel follows in a general way the course of Mud creek, it deviates at places from two to three miles to the south and to the east of it. Bedrock is not reached at 450 feet above sea level and "one well three miles north of Durant on the divide between Mud and Elkhorn creeks does not reach rock at 400 feet above sea level".[89] Well records show that the bluffs of the valley were rather steep, as the elevation of the rock surface has been found to differ as much as 250 feet within a mile. Several smaller tributaries of the Cleona channel have been mapped. From Durant the preglacial valley extends in a general direction past Wilton until it finally joins the lowland underlying the West Liberty Plain. It is not certain whether this ancient Mississippi entered the subglacial valley occupied by the present Mississippi river by way of a channel immediately south of the city of Muscatine or whether it pursued a course southward and finally followed the Iowa-Cedar river valley to the site of the buried valley at the debouchure of Iowa-Cedar river into the present Mississippi.[90]

Another large channel which undoubtedly was a tributary to the Cleona river is the Stanwood channel[91] whose course has been mapped and outlined by Norton. This ancient river flowed by Stanwood, Cedar county, then took a southerly direction, passing east of Tipton and flowing finally along the east side of the present Sugar creek valley. About two and one-half miles north of Lime City it turned southeast and near Durant joined

88 Carman. Idem, p. 58. Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 299, 1901; Geology of Scott County: Iowa Geol. Survey, Vol. IX, p. 493, 1899; Underground Water Resources of Iowa: U. S. Geol. Survey, Water Supply Paper 293, pp. 488-490, and fig. 5, 1912; Iowa Geol. Survey, Vol. XXI, pp. 587 and 588, and fig. 5, 1912.

89 Carman, Idem, pp. 58 and 59.

90 Carman, Idem, p. 58, and fig. 22. Leverett, F., The Illinois Glacial Lobe: U. S. Geol. Survey, Monograph XXXVIII, pp. 466 and 467, 1899.

91 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 297-300, and fig. 17, 1901; Underground Water Resources of Iowa, U. S. Geol. Survey, Water Supply Paper 293, pp. 368-370, and fig. 4, 1912; Iowa Geol. Survey, Vol. XXI, pp. 441-443, and fig. 4, 1912.

the Cleona channel. "Measured from crest to crest, its width is at least seven miles at Tipton."[92]

On the west side, the West Liberty lowland area may have received a tributary by way of the upper Wapsinonoc valley. A buried channel has been discovered a little west of Downey where it lies deeply hidden under the drift covering.[93] This channel probably connects with the one lying in the upper northeast corner of Johnson county, between Solon and the present Cedar river.[94]

The above described channels undoubtedly all formed part of the vast drainage system of which the master stream probably was the preglacial Mississippi river. It has been sufficiently established that the present Mississippi river is at various places occupying a valley other than that of its own making. Gordon[95] and Leverett[96] have shown that the subglacial valley is much larger than the present one, whose average width is six miles and whose depth is 150 feet as compared to the width of six to fifteen miles and the depth of 250 feet of the former valley. Between Keokuk and Montrose the present valley of Mississippi river is comparatively recent. North of Montrose to Muscatine the river is occupying the ancient valley. From Muscatine to Princeton the river is again in a newly cut valley and from the latter city up to St. Paul, Minnesota, the mighty Father of Waters is occupying the ancient valley.[97]

Such is the surface of the Lake Calvin region beneath the thick covering of drift. Because it has been invaded by glaciers several times, the former highly dissected and rough topography is now everywhere obliterated and the surface has been made relatively smooth by a thick mantle of unconsolidated drift materials which are described in the following chapter.

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92 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, vol. XI, p. 299, 1901.

93 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 326, and plate VII, 1898. Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, p. 91, 1897. Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 297 and 298, 1901.

94 Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, pp. 90 and 91, 1897.

95 Gordon, C. H., Buried River Channels in Southeastern Iowa: Iowa Geol. Survey, Vol. III, pp. 244-249, 1895.

96 Leverett, F., The Lower Rapids of the Mississippi River: Proc. Iowa Acad. Science, Vol. VI, pp. 74-93, 1899; Preglacial Valleys of the Mississippi and its Tributaries: Journal of Geology, Vol. III, pp. 740-763, 1895; The Lower Rapids of the Mississippi River: Journal of Geology, Vol. VII, pp. 1-22, 1899; Old Channels of the Mississippi in Southeastern Iowa: Annals of Iowa Historical Quarterly, (3) Vol. V, pp. 38-51, 1901; Illinois Glacial Lobe: U. S. Geol. Survey, Monograph XXXVIII, pp. 460-477, 1899.

97 For a list of the more important contributions dealing with the drainage problem of Mississippi river, the reader is referred to Appendix A.

CHAPTER IV.

THE PLEISTOCENE DEPOSITS OF THE LAKE CALVIN REGION.

All the five great continental ice incursions now recognized in North America are represented, directly or indirectly, in the Lake Calvin region.

CLASSIFICATION OF THE PLEISTOCENE DEPOSITS IN IOWA.[98]

9. Wisconsin drift (of the Des Moines lobe)
8. (b) Peorian soil and weathered zone (of Leverett) at top of loess and beneath Wisconsin drift.
   (a) Main deposit of loess.
7. Iowan drift (of Iowa geologists)[99]
6. Sangamon soil, vegetal deposits and weathered zone (of Leverett) (including super-Illinoian "gumbo", or "gumbotil" of Kay) at top of Illinoian drift and beneath loess.
5. Illinoian drift (of Leverett)
4. Yarmouth soil, vegetal deposits, and weathered zone (of Leverett) (including super-Kansan "gumbo," or "gumbotil" of Kay) at top of the Kansan drift; also Buchanan gravel (of Iowa geologists) beneath Iowan drift and loess.
3. Kansan drift (of Iowa geologists)
2. Aftonian gravels, vegetal deposits, soil and weathered zone (of Chamberlin) (including super-Nebraskan "gumbo" or "gumbotil" of Kay) at top of Nebraskan drift.
1. Nebraskan drift (of Iowa geologists) (pre-Kansan or sub-Aftonian of Chamberlin)

The Nebraskan Drift.

Distribution.—In view of the fact that the region was visited

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98 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift, A Review of the Evidences of the Iowan Stage of Glaciation: Iowa Geol. Survey, Vol. XXVI, Ann. Rep't, 1915, p. 57, 1917.

99 The Iowan stage of glaciation has now been fully established by Alden and Leighton, see previous reference, pp. 49-212.

by more than one ice sheet, exposures of the oldest drift called the Nebraskan, sub-Aftonian or pre-Kansan, are extremely rare. Practically everywhere a thick mantle of younger drift masks the older and only at a very few places, as along the base of steep slopes and along stream courses, does the Nebraskan drift come to the surface. Its presence over widespread areas seems to be revealed, however, by the records of numerous wells scattered over the region.

Exposures of the pre-Kansan drift in the lake basin or the region surrounding it have been described by Udden in his Louisa County report.[100] However, when it is remembered that the earlier investigators did not know of gumbotil or use it to differentiate one drift from another but based their partition on color, texture and petrographic content of the deposits and on intervening stratified sands and gravels, it remains an open question whether the described drifts can be proved definitely to be Nebraskan. Some of Udden's exposures listed below were seen by the writer but in only two cases (10 and 11) does the writer feel confident that the drift belongs to the oldest stage of glaciation. The drift in the other outcrops may be either Nebraskan or Kansan.

EXPOSURES OF NEBRASKAN DRIFT CITED BY UDDEN.[101]

1. On the right bank of Honey creek near the south line of Sec. 21, Tp. 73 N., R. III W.
2. On the south bank of Smith creek near the center of the Se. ¼ of Sec. 35, Tp. 73 N., R. III W.
3. In the southwest bank of Smith creek near the southeast corner of Sec. 30, Tp. 73 N., R. II W.
4. In the south bank of Long creek near the center of Sec. 22, Tp. 74 N., R. IV W.
5. In the bank of the Muscatine North and South railroad cut, in the east bluff of Iowa river, in the Se. ¼ of Sec.9, Tp. 74 N., R. III W.
6. On the west bank of Iowa river at Wapello.

100 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, pp. 55-126, 1901.
101 Idem, pp. 103 and 104.

7. On the west bank of Iowa river one mile north of Columbus Junction and farther north.
8. In the west bank of Cedar river two miles north of Columbus Junction.
9. In the railroad cuts in the bluffs of Mississippi river in Sec. 2, Tp. 75 N., R. III W.
10. Foot of the west bluff of Iowa river, along the wagon road in the Se. ¼ of Sec. 21, Tp. 76 N., R. V W.
11. East bank of the Iowa, on both sides of the north line of Sec. 16, Tp. 76 N., R. V W.

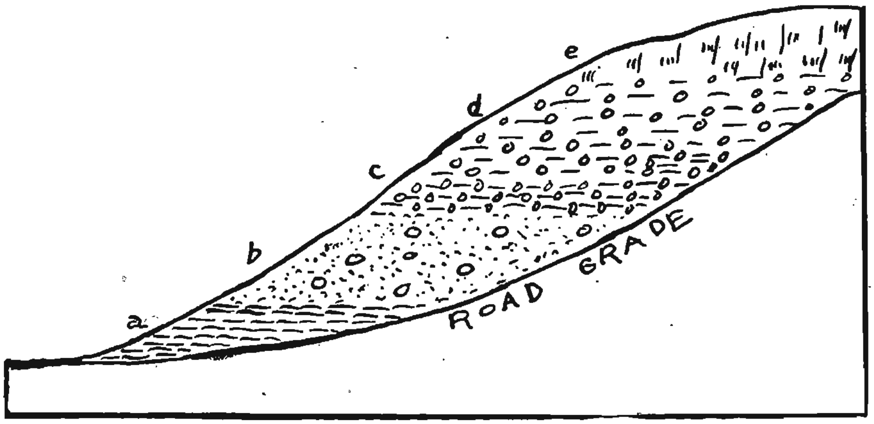

FIG. 7.—Relations of strata of drift seen on the south side of the road leading down the Iowa river bluff in the Se. ¼ of sec. 21, Tp. 76 N., R. V. W. *a* Black, tough, leached silty soil (top of Nebraskan till ?); *b* tough bowlder clay with ferruginous joints, yellow above, grayish blue below (Kansan); *c* somewhat stratified and sandy, yellow till; *d* leached horizon (Sangamon; *e* loess. (After Udden.)

Udden, in describing the Nebraskan,makes the following statement regarding locality 10 and presents the figure (Fig. 7) given below. "In one instance there seems to be a soil horizon on its upper surface."[102] At the time of the writer's visit to the exposure, *a,* the black tough soil horizon, was not seen, due to heavy slump. However, *b, c, d,* and *e* were visible and *d* proved to be a typical gumbotil. Because of its topographic position and elevation, about 640 feet above sea level, the writer believes the gumbotil to be super-Nebraskan and the till beneath, Nebraskan. Two miles both north and south of this exposure undoubted Kansan gumbotil is found at 710 feet. Unless the present conception of the origin of the gumbotil is erroneous, no such big

102 Idem, p. 104, and fig. 3.

difference in elevation in the same gumbotil within such a short distance is permissible. The only outcrops of the Nebraskan drift in Muscatine county are found in the vicinity of Muscatine. No exposure of the oldest drift in Cedar county is reported although wells sunk over the Stanwood channel penetrate it.[103] Exposures of the pre-Kansan drift were not known to occur in Johnson county until 1916 when the writer discovered along the bluff line of the extinct lake a true gumbotil lying between two drifts. This gumbotil and the drifts are exposed in two road cuts, separated by about four-tenths of a mile. Midway between the two outcrops and at approximately the same elevation, the presence of the gumbotil is indicated by a strong flowing spring. As the upper drift is undoubted Kansan, the lower must be the Nebraskan. The two exposures are in West Lucas township in the southeast quarter of section 33. The first outcrop is the west bank of the cut along the road where it descends from the upland to the lowland in the extreme southeast corner of the section. The other exposure is four-tenths of a mile to the northwest of the first exposure. A third outcrop of what seems to be Nebraskan drift was discovered by the writer in the north bank of Davis creek, in the extreme southwest corner of section 36, Iowa township, Washington county. This till, which is dark, dense and bluish, is separated from a light pebbly fresh brown till by about twenty feet of highly oxidized and leached stratified sands and gravels which the writer believes to have been weathered during the interglacial interval separating the Nebraskan from the Kansan stage of glaciation.[104] This exposure lies 640 feet above sea level or approximately ten feet lower than the super-Nebraskan gumbotil in Johnson county. Because of its stratigraphic position and its close proximity either to the leached and oxidized sands and gravels in Washington county or to the super-Nebraskan gumbotil in Johnson county, the drift seen at the following places may be mentioned as probably being Nebraskan.

1. Johnson county, Liberty township, section 27, Ne. ¼, west river bank.

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103 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 344, 1901.
104 Schoewe, W. H., The Interpretation of Certain Leached Gravel Deposits in Louisa and Washington Counties, Iowa: Proc. Iowa Acad. Science, Vol. XXVI, pp. 393-398, 1919.

2. Johnson county, Fremont township, section 24, Sw. ¼, east river bank.
3. Johnson county, Fremont township, section 25, Se. ¼, west part, east river bank.
4. Johnson county, Pleasant Valley township, section 23, Ne. ¼, northwest part, east river bank.
5. Washington county, Iowa township, section 23, Nw. ¼, northeast part, west bank of river.
6. Louisa county, Union township, section 6, northcentral part, south bank.
7. East bank of Iowa river on both sides of the north line of section 16, Tp. 76 N., R. V W. (Udden's exposure 11, see page 90.)

Character of the Drift.—The Nebraskan till in its unweathered state consists of a hard, dark brownish to blue-black, calcareous, compact, joint clay, which contains at places many fragments of wood. The till breaks into small angular to rhomboidal blocks. Where this till has been seen, most of the pebbles which are scattered throughout its mass are small and cobbles or bowlders are relatively few. At exposure 7 above, or 11 of Udden's outcrops, the clay appears to be without pebbles and finely laminated. Numerous cobbles and bowlders of all descriptions and sizes are to be found lying on the surface of the till, which in most cases forms a sort of bench. Many of these stones are striated and a large number of the granitic type are thoroughly disintegrated and break into thousands of pieces when stepped on. It is also noticeable that wherever these cobbles and bowlders occur, an unusual proportion of them are flattish or slablike.

The weathered phase of the pre-Kansan drift has been oxidized to a brownish color. It is not as compact as the unweathered phase and apparently does not differ from the weathered phase of any of the younger drift sheets. According to Udden, the Nebraskan drift "contains about twice as many fragments of local rocks"[105] such as the Kinderhook and Burlington formations, as do other drifts. Also accord-

105 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 102, 1901; Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, see table on p. 336, 1899.

ing to the same observer, more greenstone hornblendic rocks as well as schists and a smaller proportion of dolomitic limestone and rocks common in the Keweenawan are found in the Nebraskan than in other drifts.

Thickness of the drift.—The maximum thickness seen, either of the fresh or of the weathered drift, is no more than ten feet. Due to heavy slumping, the thickness of the Nebraskan north of Gladwin at the outcrop in the west bluff of Iowa river, along the wagon road in the Se. 1/4 of sec. 21, T. 76 N., R. V W., and at Indian lookout in Se. 1/4 of sec. 33, West Lucas township, Johnson county, could not be ascertained, but a fair estimate of thirty to forty-five feet could not be overconservative. It appears that on the whole the Nebraskan drift is thin and is absent from the uplands except where the preglacial surface was low.[106] Even in the low places it was found sparingly.[107] According to Leighton[108] a study of well records in Johnson county gives the Nebraskan the following thickness: 15, 15, 25, 54, 86 and 122 feet. Udden[109] reports ten to twenty feet for the thickness of the drift in Louisa county, and Norton[110] reports a thickness of sixty-five feet in Cedar county.

The Aftonian Deposits [111]

The gumbotil.—The only true deposits of the first interglacial stage outcropping in the lake region are the super-Nebraskan gumbotils exposed at three places along the bluff line of Lake Calvin. The first two outcrops are in Johnson county in the southeast quarter of section 33 of West Lucas township. The third exposure is in Louisa county in the southeast quarter of section 21, Union township. This gumbotil,[112] which is believed to be the oxidized and leached pro-

106 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 103, 1901.

107 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 338, 1899.

108 Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV, pp. 169-181, 1914.

109 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 103, 1901.

110 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 344, 1901.

111 At the time of this writing the term Aftonian as the name of the first interglacial deposits is in question since doubt is being raised as to whether the type section of the Aftonian sands and gravels at Afton Junction is a true interglacial deposit.

112 Kay, George F., Gumbotil, A New Term in Pleistocene Geology, Science, New Series, Vol. XLIV, Nov. 3, 1916; Pleistocene Deposits between Manilla in Crawford County and

duct of the drift, is a drab or ash-colored, thoroughly leached, hard and tough clay containing but few pebbles. The contained pebbles are small and consist of the more insoluble matter such as quartz, chert and quartzite; other constituents, however, as granites and basalts, are not entirely wanting. A microscopic analysis[113] shows that the gumbotil is made up of sixty to seventy-five per cent of minute, spherical, transparent grains of quartz and twenty-five to forty per cent of clay. When it is wet, the gumbotil breaks with a starchlike fracture and when it is dry its surface has a characteristic checkered appearance. A thickness of only about ten feet could be determined definitely at the exposures in Johnson county, due to heavy slumping, and only four feet at the third exposure. In Johnson county a brownish till sheet lies on top of the gumbotil and another lies beneath it, whereas in Louisa county it is overlain by a loess and underlain by a brown to yellowish sandy till. The gumbotil in Louisa county is believed to be Nebraskan rather than Kansan. Two miles to the north and at a similar distance to the south from the outcrop is another gumbotil lying at an elevation of 705 to 710 feet above sea level. At these places the gumbotil lies fifteen to twenty feet below the general level of the upland and is Kansan. As the elevation of the gumbotil in the southeast quarter of section 21 is about 640 feet, the original gumbotil plain, if all of the gumbotils are of the same age, has a slope of seventy feet in two miles or thirty-five feet per mile. Since it is believed that the plain on which the gumbotil was formed was essentially a ground moraine like that of the Wisconsin stage of glaciation in northcentral Iowa and that erosion was slight,[114] it is believed that a plain with a relief of thirty-five feet per mile is not in harmony with the idea of the origin of gumbotil.

A deposit which is possibly gumbotil has been reported by

Coon Rapids in Carroll County, Iowa: Iowa Geol. Survey, Vol. XXVI, p. 217, 1915; The Origin of Gumbitil, (with J. N. Pearce): Jour. of Geology Vol. XXVIII, No. 2, pp. 89-125, Feb.-Mar. 1920.

113 Dewey, Arthur H., The Pleistocene History of Lee County, Iowa. Unpublished thesis, Library, State University of Iowa, 1917.

114 Kay, G. F., Some Features of the Kansan Drift in Southern Iowa: Bull. Geol. Soc. of America, Vol. XXVII, pp. 115-117, 1915. Reprinted in Iowa Geol. Survey, Vol. XXV, pp. 612-615, 1914.

Leighton[115] as outcropping along the west bluff of Iowa river a few miles north of Coralville in section 33, Penn township, Johnson county. The writer in company with Mr. A. H. Dewey visited the section and found there what might be interpreted as a gumbotil, but due to the slumping of early spring, it was impossible to determine its thickness or whether it was in place.

Leached sands and gravels.—The only other visible evidence of this first interglacial interval is found in the following two places:

1. Washington county, Iowa township, section 36, extreme southeast corner, north bluff of Davis creek.
2. Louisa county, Union township, section 8, Nw. ¼, Sw. ¼, south wall of Goose creek.

At these places occur highly oxidized and leached stratified sands and gravels above which is fresh oxidized till, and, in the outcrop in Washington county, dense bluish compact unaltered till. The leaching and oxidation of these sands and gravels is believed to represent the time interval between the Nebraskan and Kansan stages of glaciation.[116]

Other interglacial deposits.—Aside from the above described interglacial deposits, numerous other sands and gravels, silts, soil bands and peat beds have been described in the various geologic county reports of the region as being Aftonian.[117] These deposits, most of which are lying at a considerable depth below the surface, are revealed in the logs of wells. Those in Louisa county range in thickness from two to ten feet, those in Muscatine from eight to fourteen feet and those in Johnson county from four to sixty-eight feet.

The Kansan Drift.

Distribution.—Except for the eastern border of the lake basin in Muscatine county and several small areas in the

115 Personal communication to Dean G. F. Kay.

116 Schoewe, W. H., The Interpretation of Certain Leached Gravel Deposits in Louisa and Washington Counties, Iowa: Proc. Iowa Acad. Science, Vol. XXVI, pp. 393-398, 1919.

117 Calvin, S., Geology of Johnson County: Iowa Geol. Survey, Vol. VII, 1897. Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, 1899; Geology of Louisa County: Iowa Geol. Survey, Vol. XI, 1901. Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, 1901. Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City, in Johnson County: Iowa Geol. Survey, Vol. XXV, (1914), 1916.

northern portion of the lake region, the Kansan is the uppermost drift under practically the entire area. This drift is either exposed at the surface or it lies directly below a more or less heavy mantle of loess. As exposures may be seen almost everywhere along road cuts, along the valley walls of Iowa and Cedar rivers as well as along some of the smaller streams, no detailed locations need be cited.

Character of the drift.—Several phases of the Kansan drift sheet were noted; namely, the fresh or unaltered phase, the oxidized but unleached phase and the oxidized and leached phase. The unchanged till consists of a very compact, dense material of a bluish color in which the pebbles are predominantly small and which at places contains numerous fragments of wood. This phase of the Kansan till is rarely represented in the outcrops by a thickness of more than a few feet. Overlying the unoxidized and unleached material is a gray or yellowish to brownish sticky clay containing numerous striated and subangular pebbles, cobbles and bowlders of all descriptions. In most places the till is very sandy and in the vicinity of Columbus Junction an unusual amount of limestone is noticeable. Small rounded quartz, chert and greenstone pebbles also are numerous throughout this phase of the till. Large bowlders of granite, dolerite and basalt are in evidence practically everywhere. Some of these are highly weathered and crumble to pieces on slight pressure, whereas others are very hard and show no trace of alteration. It was noted that in Johnson, Louisa and Washington counties, among the gravels and bowlders lying on the surface of the Kansan drift within the lake basin near to the bluff line, a fair proportion are more or less slablike instead of having the characteristic subangular form. In Johnson county the Kansan drift is relatively free from large bowlders except locally as in the tributary gullies of Iowa river north of Iowa City where numerous large fresh bowlders of various kinds have been concentrated.[118] According to Udden[119] a larger proportion of diabase, granite and

118 Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), p. 119, 1916.

119 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 105, 1901.

other Keweenawan pebbles are found in the Kansan of Louisa county than in the Nebraskan, whereas the number of limestone and dolomite pebbles is the same in the two drifts.

Except for the absence of the calcareous constituents, the oxidized and leached zone of the Kansan drift is in all respects similar to that of the oxidized and unleached portion just described. It may be noted that very often the uppermost foot or two of the altered drift is very highly oxidized to a reddish brown color and is thus set off from the other portions of the drift. This thin zone is known as the "ferreto" zone.

Thickness of the drift.—The Kansan drift differs in thickness from place to place, being thinnest where it rests on bedrock. Where the drift was seen lying directly on the country rock in Morning Sun township, Louisa county, its thickness scarcely anywhere exceeds twenty feet and at the Interurban cut on the west side of Iowa river at Iowa City, its thickness is not quite eight feet. The maximum thickness of this till which was seen in the field is about sixty feet although well records in Johnson county, as shown by Leighton,[120] indicate a thickness of over 200 feet. Udden[121] reports a maximum of 100 feet for Muscatine county. In general the leaching of the Kansan drift has not penetrated farther down than five to thirteen feet,[122] whereas the oxidation as observed in the field has in many cases extended to a depth of sixty feet or more.

The Yarmouth Interglacial Deposits.

The Kansan gumbotil.—The second or Yarmouth interglacial stage is represented mostly by exposures of gumbotil and Buchanan gravels. Numerous well records throughout the region reveal also a soil and peat horizon. The Kansan gumbotil in its physical and chemical properties is in all respects similar to the Nebraskan. At most places the gumbotil is overlain by leached loess although a few outcrops show oxi-

120 Leighton, Morris M., The Pleistocene History of Iowa River Valley North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914) p. 118, 1916.

121 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 339, 1899.

122 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI (1915), pp. 85-87, 1917.

dized Illinoian till above the gumbotil. Its thickness where it may be seen ranges from six to eleven feet. This small range of thickness, however, does not, in all probability, represent the entire development of this material, for in most instances the outcrops were either in shallow road cuts or else were hidden by more or less slumping. An average thickness of fifteen feet probably would not be far from correct, especially as that is the average thickness of the Kansan gumbotil in nearby counties.[123] In altitude the Kansan gumbotil plain ranges from 670 to 750 feet above sea level, being higher toward the western portion of the lake region.

The Buchanan gravels.—Most of the Buchanan gravels to be seen in the lake region are those described by Leighton.[124] Similar deposits are exposed in Iowa City on the north side of Brown street near Dubuque street, at the T-road in the center of section 16, West Lucas township, south of the city, and in the walls of the gully immediately south of the railroad tracks of the branch line of the Chicago, Rock Island and Pacific Railway where it crosses Iowa river.

The Buchanan deposits consist of highly oxidized and decayed stratified sand and gravel whose textural range is from fine sand to bowlders one foot or so in diameter. Many of the sands and gravels are of a highly reddish color and at places show crossbedding and contortion.[125] Calvin[126] has divided the Buchanan gravels into two phases, the upland phase and the valley phase, the former consisting of the coarser and bowldery material, the latter of the sand and finer pebbly gravel. Calvin regarded the Buchanan gravels as Kansan outwash, the upland phase having been deposited while the valleys were still filled with ice and the valley phase having been laid down in connection with the retreat of the ice

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123 Dewey, Arthur H., The Pleistocene History of Lee County, Iowa, Unpublished thesis, Library, State University of Iowa, 1917.

124 Leighton, Morris M., Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), pp. 120-124, 1916.

125 Idem, pp. 142-146; An Exposure showing post-Kansan glaciation near Iowa City, Iowa: Jour. Geology, Vol. 21, pp. 431-435, 1913. Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI (1915), pp. 117-118, 1917.

126 Calvin, S., Geology of Buchanan County: Iowa Geol. Survey, Vol. VIII, pp. 201-253, 1898.

sheet.[127] Leighton[128], however, has come to the conclusion that Calvin's valley phase or terrace gravels represent Iowan outwash deposits.

Sand and gravel deposits in Muscatine county.—Deposits of highly oxidized coarse sand and fine pebbles, very similar to Calvin's valley phase of Buchanan gravels, are exposed in Muscatine county at the following four localities:

1. Goshen township, center of section 11, east road cut of north and south road.
2. Goshen township, southwest corner of section 9, road cut.
3. Goshen township, corner of south section line of section 10.
4. Wapsinonoc township, center of section 26.

With the exception of locality 4, all of the outcrops are in road cuts in the bluff line of the old lake. The deposits consist of highly ferruginous or brownish red coarse sand and fine pebbles. The pebbles are almost all well rounded and some are striated. The material is leached as is the underlying till. In all three of the exposures in Goshen township, the sands and pebbles are covered by a deposit of loess or loess-like clay most of which is leached. In section 9 the sandy material is covered by eight inches of sticky gray clay containing small chert pebbles, and in section 10 the underlying till, which is rather sandy at places, contains pockets of a similar very sticky leached clayey material containing quartz and chert pebbles. This clayey deposit may represent a gumbotil, a soil bed or a lake deposit. Only at two places, in sections 10 and 11, could the thickness of the sands and gravels be determined. In the former cut, four feet of sand is exposed, whereas in the latter exposure the thickness of the deposit ranges from ten to fifteen feet. In all four instances, the sand and pebbles were practically at the same height above the adjacent flat or terrace, namely twenty to thirty feet, or at an elevation of 685 to 695 feet above sea level. If these de-

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127 Leighton, Morris M., The Buchanan Gravels of Calvin and the Iowan Valley Trains: Proc. Iowa Acad. Science, Vol. XXIV, p. 86, 1917.

128 Idem, p. 86.

posits are Buchanan gravels, then they correspond to Calvin's valley phase, as they are very much finer than the Buchanan gravel deposit of the interurban cut at Iowa City which is, according to Leighton,[129] the upland phase. From their topographic position it is clearly evident that these four deposits, although resembling the valley phase very closely, cannot be valley train deposits from the Iowan ice as Leighton[130] suggests for Calvin's valley phase. The presence of the sticky clay overlying the sands at one locality and the remarkable coincidence of elevation and height above the lowland or terrace suggest the possibility that the deposits may represent a highly oxidized beach deposit of a former body of water.

Other Yarmouth deposits.—Other and similar deposits representing Yarmouth times are described as occurring in Louisa, Cedar and Johnson counties. Udden[131] described a somewhat gravelly sand as well as soil bands which he found in Louisa county. Norton[132] reports one exposure in Cedar county which showed a dark red sand containing disseminated pebbles and Leighton[133] refers to the Buchanan gravels as being encountered in numerous wells in Johnson county.

The Illinoian Drift.

Distribution and character.—The Illinoian drift forms the surface material in those parts of Muscatine and Louisa counties which lie east and south of the lake basin. While it is characterized by a somewhat lighter yellowish color and a more sandy nature, the Illinoian drift to all other appearances closely resembles the Kansan and the Nebraskan drift sheets. Not only is the thickness of this drift less than the thicknesses of the other two, but leaching and oxidation have

129 Leighton, Morris M., Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), p. 120, 1916.

130 Leighton, Morris M., The Buchanan Gravels of Calvin and the Iowan Valley Trains: Proc. Iowa Acad. Science, Vol. XXIV, p. 86, 1917.

131 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, pp. 105-107, 1901.

132 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, pp. 366-367, 1901.

133 Leighton, Morris M., Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV (1914), pp. 123, 169-181, 1916.

not progressed nearly so far. Where the drift has been examined, leaching has not been found to penetrate more than two or three feet although oxidation, at one place which was observed, has penetrated to a depth of thirty-nine feet. The Illinoian drift, on the whole, is very thin, at places being no more than two feet thick and in some places being lacking entirely. An average thickness for this drift where it has been observed is considerably less than thirty feet.

Sangamon Deposits.

Gumbotil and peat beds.—Deposits of gumbotil, peat and old soils register the third or Sangamon interglacial stage. The Illinoian gumbotil, in general, is in all respects, except thickness, similar to the Kansan and Nebraskan gumbotils. Its average thickness is but five feet. Outcrops are numerous on the slopes of the ravines which dissect the level Illinoian upland. Exposures of gumbotil are numerous also on both valley walls of the Iowa-Cedar river valley below Columbus Junction. At several places, as in the cut along the railroad tracks between Bard and Columbus Junction, on the line between sections 33 and 34, and in the north bluff of Iowa river, southwest corner of section 10, Port Louisa township, two and one-half miles north of Wapello, a soil or peat bed overlies the gumbotil. Most of the gumbotil at these places is highly carbonaceous. The peat bed in section 10 is five feet thick and the upper two feet is almost entirely woody. Fossil beetle remains were observed in the peat, but due to the poor state of preservation and the burning of the peat several years ago, their identity could not be ascertained. This peat horizon also has been described by Alden[134] and has been referred to by Udden.[135] Both of these writers are of the opinion that the peat is of Sangamon age. A comparison of elevations of the gumbotil along the valley walls and on the Illinoian upland, (see table 2, page 102, seems to indicate that a large sag existed over the present valley of Iowa-Cedar river after the retreat

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134. Alden, Wm. C., and Leighton, Morris M., the Iowan Drift: Iowa Geol. Survey, Vol. XXVI (1915), p. 169, 1917.

135 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 109, 1901.

TABLE. 2. TABLE OF GUMBOTIL ELEVATIONS AND SLOPES OF RECONSTRUCTED GUMBOTIL PLAINS IN THE REGION OF THE IOWA-CEDAR RIVER VALLEY.

	Location	Topographic Position	Elevation	Difference in Elevation, Ft.	Distance Miles	Slope, Feet per mile, Reconst'd. Gumbotil Plain.
1	Section road between sections 25 and 30, 1 mile south of Columbus Junction	Upland	710			
2	Northeast corner of NW¼, section 35, 2½ miles east of Cairo	Upland	700	10	7.5	1.3
3	Center of NW¼, section 14, 1½ miles northwest of Oakville	Upland	650	50	12.5	4.
4	Intersection of road and Illinoian bluffs in section 22, 2 miles east of Fredonia	Valley walls	640			
5	East central part of section 5, Port Louisa township	Valley walls	620	20	5.5	3.6
6	North central part of NW¼, section 9, Port Louisa township	Valley walls	615	5	1.	5.
7	Northwest corner, section 15, 2½ miles north of Wapello	Valley walls	610	5	1.25	4.
8	West central part, section 23, 1½ miles northeast of Wapello	Valley walls	610	0	2.25	0.
9	South central part, section 31, 3¼ miles southeast of Wapello	Valley walls	600	10	3.—	3.3
10	Northeast corner along section road between Secs. 9 and 16, 2½ miles northeast of Elrick	Valley walls	610	10	3.25	3.
11	Northeast corner along section road between Secs. 15 and 22, 1¾ mi. northwest of Oakville	Valley walls	620	10	1.5	6.6
	1—4	Upland to valley walls	710-640	70	3.75	19.—
	2—7	Upland to valley walls	700-610	90	5.5	16.+
	3-11	Upland to valley walls	650-620	30	1.	30.

of the Illinoian ice sheet. Such a sag as must have existed if the gumbotil along the valley walls is Illinoian does not appear to be in harmony with the gumbotil hypothesis or with the existence of Lake Calvin. The table shows that the slope of the gumbotil plain when it is reconstructed from the three upland gumbotil outcrops ranges from one and three-tenths to four feet per mile and that the plain determined from the elevations of the gumbotil exposed along the valley walls has a slope of less than seven feet per mile. On the other hand, it is also seen that when all elevations are considered, a minimum slope of sixteen feet per mile is obtained. This figure is undoubtedly too small. There is a difference of thirty feet in the elevations of the two outcrops of gumbotil in sections 14 and 15, about one and one-half miles northwest of Oakville. The exposures are but one mile apart, the former being on the upland, the latter along the valley walls. At the other places where a similar comparison is made, the outcrops are separated by the Iowa-Cedar river valley which has a width of three and three-fourths to five and one-half miles, thus giving the low figures of sixteen and nineteen feet per mile indicated in the table. Since the slopes of the reconstructed gumbotil plains when they are considered independently are in perfect agreement but when treated collectively are not in harmony with the gumbotil hypothesis or with the existence of Lake Calvin, the writer has come to the conclusion that the gumbotil and peat exposed along the valley walls of the Iowa-Cedar river valley are not Sangamon in age. They may well represent Yarmouth deposits or possibly even those of the first interglacial stage. In this connection, it is suggested that a detailed study of the Iowa-Cedar river valley might prove of great value in the study of the origin of the gumbotils. Numerous exposures of soil bands and peaty deposits in Louisa and Muscatine counties are described by Udden[136] and Leighton and Alden[137] have described several outcrops of gumbotils in Louisa county.

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136 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, pp. 109-111, 1901.

137 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI (1915), pp. 168-171, 1917.

The Iowan Drift.

Distribution and character.—Unlike the Kansan and Illinoian drift sheets the Iowan in the lake region does not constitute a continuous surface formation, but occurs in five lobate extensions of the main drift sheet in the northern portion of the region. Although they possess some characteristics of the typical Iowan drift plain, a question has recently been raised concerning all but the westernmost tracts[138] as to their ever having been covered by the Iowan ice sheet. Exposures of drift in this younger drift plain are rare, because little dissection has taken place since the deposition of the drift. The Iowan area is characterized by its youthful topography, its absence of a loess covering and the presence of huge coarse-grained granitic bowlders. The till itself is not distinctive. In contrast with the Kansan till, the Iowan till is more sandy and porous and has a yellowish color. Oxidation has penetrated but eight or ten feet and leaching on an average between three and five and one-half feet. This bowlder clay is characterized by a low content of calcium carbonate.[139] The unleached portion of the till is darker than the leached portion and from a bluish or drab gray to a slate color. On the whole, the fresh till is somewhat harder and denser than the oxidized portion. Many of the contained pebbles and bowlders exhibit a marked degree of freshness. The Iowan drift is thin, probably averaging no more than ten feet.[140]

The Peorian Interglacial Deposits.

Loess.—The fourth or Peorian interglacial stage is represented in the lake region by the widely known loess deposits. The loess consists of unstratified, usually yellowish to buff-colored siltlike material which is composed of very fine angular particles of quartz, feldspar, mica, and ferromagnesian and other minerals. The deposit is somewhat sandy, but pebbles are lacking from the typical loess. It can be easily detected

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138 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI (1915), pp. 177, 179, 180, 1917.

139 Calvin, S., Present Phase of the Pleistocene Problem in Iowa: Bull. Geol. Society of America, Vol. 20, p. 145, 1909.

140 Calvin, S., Iowan Drift: Bull. Geol. Society of America, Vol. 10, p. 113, 1899.

by its remarkable ability to stand in vertical faces for a long time after being exposed. The loess where it is unleached generally contains the fragile shells of small land snails and peculiar shaped calcareous nodules known by the name of "loess-kindchen." Cylindrical hollow tapering limonite concretions are common in the upper portion of the deposit, which in many places is completely leached of its calcium carbonate content. Practically nowhere has the leaching penetrated to a greater depth than eight to ten feet. The thickness of the loess differs from place to place from a probable maximum thickness of thirty feet to nothing more than a thin veneer. The loess is found not only on both the Kansan and Illinoian uplands, but is present also in the lake basin itself, although not to a great extent.

The Wisconsin and Post-Wisconsin Deposits.

Wisconsin terraces and valley train deposits.—The only deposits in the lake region which are known to represent the Wisconsin stage of glaciation are the sands and gravels of a few scattered terraces in some of the tributary valleys of the Mississippi, and the Wisconsin valley train deposit in the Mississippi gorge. Since these deposits, however, bear no intimate relation to the origin and history of Lake Calvin, a further discussion of them is not warranted. Future work may demonstrate that the terrace materials in the Iowa-Cedar valley between Columbus Junction and Mississippi river are associated with the Wisconsin stage of glaciation.

Recent deposits.—Post-Wisconsin deposits are the alluvium of the present flood plains of the rivers, some of the sand dunes bordering the stream courses and most of the upper soil deposits.

History of the Pleistocene Formations.

After the deposition of the last marine sediments, probably the Des Moines formation of the Pennsylvanian period, the region later occupied by Lake Calvin was subjected to a long interval of erosion. As a study of well records and outcrops of the indurated rock shows, the subglacial topography consists of a rough country traversed by numerous large drainage channels. Whether the first great continental ice sheet, the Nebraskan, advanced over a highly dissected region very much like the famous Driftless Area of southwestern Wisconsin and adjacent states or whether the region had been reduced again to one of low relief[141] has not been demonstrated. The fact remains that the lake region was invaded by the Nebraskan ice sheet and from the evidence of the Nebraskan gumbotil it is deduced that the region after the retreat of the glacier presented a level ground moraine topography similar to that of the Wisconsin drift plain in the northcentral part of the state.

The advent of the next ice sheet, the Kansan, was preceded by a very long erosion interval. During this stage, known in literature as the Aftonian interglacial stage, atmospheric weathering attacked the materials of the newly formed drift sheet and oxidized and leached the upper part of the drift until it became a tough, sticky drab colored gumbotil which now is ten to fifteen feet in thickness. Presumably contemporaneously with the formation of the gumbotil, the sands and gravels in Washington and Louisa counties which have been described above were leached and oxidized. The presence of soil bands and stratified sands and gravels has suggested to some that the Aftonian interglacial interval "was a time of luxuriant forests . . . an interval of moist climate and swollen streams."[142] From studies and discoveries in other sections of the country, it is known that during this mild interglacial stage such mammals as the elephant, the mastodon, the horse and the great stag roamed over the state.[143] After a prolonged period of weathering, diastrophic movements elevated the region and erosion became the dominant process causing the dissection of the original gumbotil plain.

The period of erosion was gradually followed by changes in the climate during which it became colder and colder until finally the lake region was invaded from the north by a second

141 Professor Trowbridge is of the opinion that the Nebraskan ice sheet advanced over a peneplain.

142 Calvin, S., Present Phase of the Pleistocene Problem in Iowa: Bull. Geol. Society of America, Vol. 20, p. 139, 1909.

143 Hay, O. P., The Pleistocene Mammals of Iowa: Iowa Geol. Survey, Vol. XXIII, 1913.

ice sheet, the Kansan. All the existing valleys were filled up with the glacial debris, the relief was reduced and a new ground moraine upon which new drainage courses were established was left by the retreating ice sheet. A long period of weathering followed during which fifteen to twenty feet of super-Kansan gumbotil was formed and the Buchanan gravels and sands were oxidized and leached. Another rejuvenation of the land set in, resulting in erosion and dissection of the gumbotil. It was during this time that the present course of Iowa river and undoubtedly that of the Cedar were established. That this, the Yarmouth interglacial stage, was of longer duration than the Aftonian seems to be indicated by the thicker layer of gumbotil formed during that time. Whether pronounced erosion again took place is difficult to state as records of post-Nebraskan, pre-Kansan erosion are not available. However, evidence[144] tends to show "that quite an amount of erosion had probably taken place in the surface of the Kansan before the Illinoian drift was deposited."[145]

For a third time, a period favorable for the formation of glaciers set in. This time, however, the entire lake region was not invaded by the oncoming ice sheet, which moved from the Labradorian center. Only the eastern portion of the area under discussion was traversed by an extension of the Illinoian glacier which pushed its way from the state of Illinois across the valley of Mississippi river into Iowa. It was the displacing of Mississippi river by the ice invasion which gave rise to the ponding back of the combined water of Mississippi, Cedar and Iowa rivers, forming Lake Calvin. The withdrawal of the Illinoian ice sheet was followed by a long period of gumbotil and peat formation. Due either to diastrophic movements or because of the proximity of the Lake Calvin region to the unaffected parts of the Mississippi river valley, erosion then set in and began to incise the recently formed gumbotil plain. It may be that during this stage of erosion Lake Calvin was finally drained and dissection of the lake basin was inau-

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144 Leverett, F., The Weathered Zone (Yarmouth) between the Illinoian and Kansan Till Sheets: Proc. Iowa Acad. Science, Vol. V, pp. 81-85.

145 Calvin, S., Present Phase of the Pleistocene Problem in Iowa: Bull. Geol. Soc. America, Vol. 20, p. 142, 1909.

gurated. This stage of nonglaciation which is known as the Sangamon interglacial stage, was followed by a fourth ice incursion, the Iowan, which affected only the northernmost part of the lake region. In connection with this ice sheet, terraces of sand and gravel were formed along some of the stream courses leading away from the melting glacier as well as in the lake basin. During the ensuing interglacial stage, the Peorian, loess was deposited over most of the region and dissection of the Iowan terrace began. The dissection may have been temporarily halted during the Wisconsin stage of glaciation by the ponding back of Iowa and Cedar rivers due to the filling up of the Mississippi valley by deposits of Wisconsin outwash materials. Erosion, however, soon became active again and caused the further removal of the Iowan terraces and the building up of the present flood plains of the rivers, a process which is still in operation.

CHAPTER V.

THE PHYSIOGRAPHY OF THE LAKE CALVIN BASIN.

Shape and Extent of Lake Basin.

Shape.—The shape of the basin formerly occupied by Lake Calvin when considered in its broad general outline is that of a huge letter "V" made irregular by numerous ramifications, which are found especially in the northern part of the lake site. The arms of the "V" extend in a direction parallel to Iowa and Cedar rivers and form its apex near the junction of the two streams at Columbus Junction, Louisa county. (See Plate VI, Map of Lake Calvin.)

Extent.—If we do not consider the numerous river-like irregularities north of Iowa City, West Liberty and Moscow as being part of the lake basin proper, the lengths of the Iowa and Cedar river arms of the "V" are twenty-eight and twenty-four miles respectively, with corresponding average widths of four and four-tenths and five and eight-tenths miles. The widest portion of the lake site is two and one-half miles south of Lone Tree where the two bluff lines are separated by a low flat stretch of country fourteen and two-thirds miles in extent. Of the three ramifications which may be considered as belonging to the main basin, the English river extension, which branches off the Iowa river arm in Washington county, is the largest. Its length and average width are fifteen miles and one-half mile respectively as compared to the length of ten miles and the breadth of somewhat over a mile of the Old Mans creek ramification, the northern branch of the Iowa river arm of the "V". The third of the secondary continuations of the lake basin is Wilton valley in Muscatine county. Its length may be considered as being that part of the valley lying between the villages of Moscow on the west and Durant on the east, a distance of eight and one-half miles. At the time of their greatest expansion, the waters of the lake covered an area of approximately 325 square miles or 208,000 acres, an area, as may be seen from figure 8, equal to about three-fourths of Muscatine county. Following the shore line of Lake Calvin during this stage of maximum development would have been equivalent to taking a journey of 475 miles, which is less by twenty-five miles than the distance between Chicago and Council Bluffs.

Uplands.—As indicated elsewhere, the extensive lowland area of the Lake Calvin basin is surrounded by uplands consisting of the Kansan, Illinoian and Iowan drift plains. Of these highlands, which rise eighty to one hundred feet above

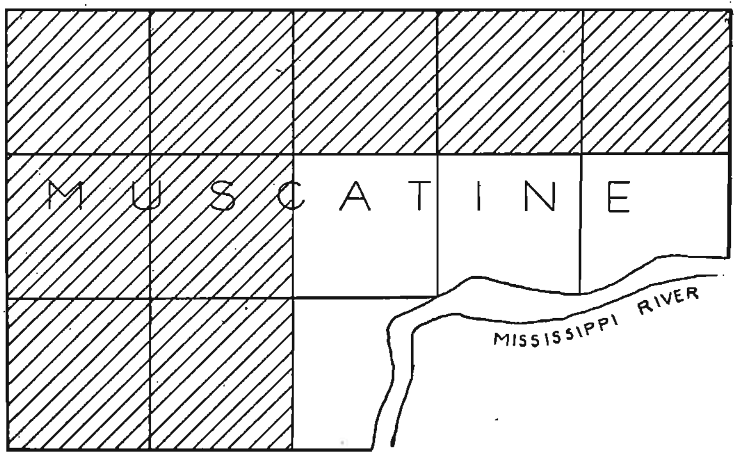
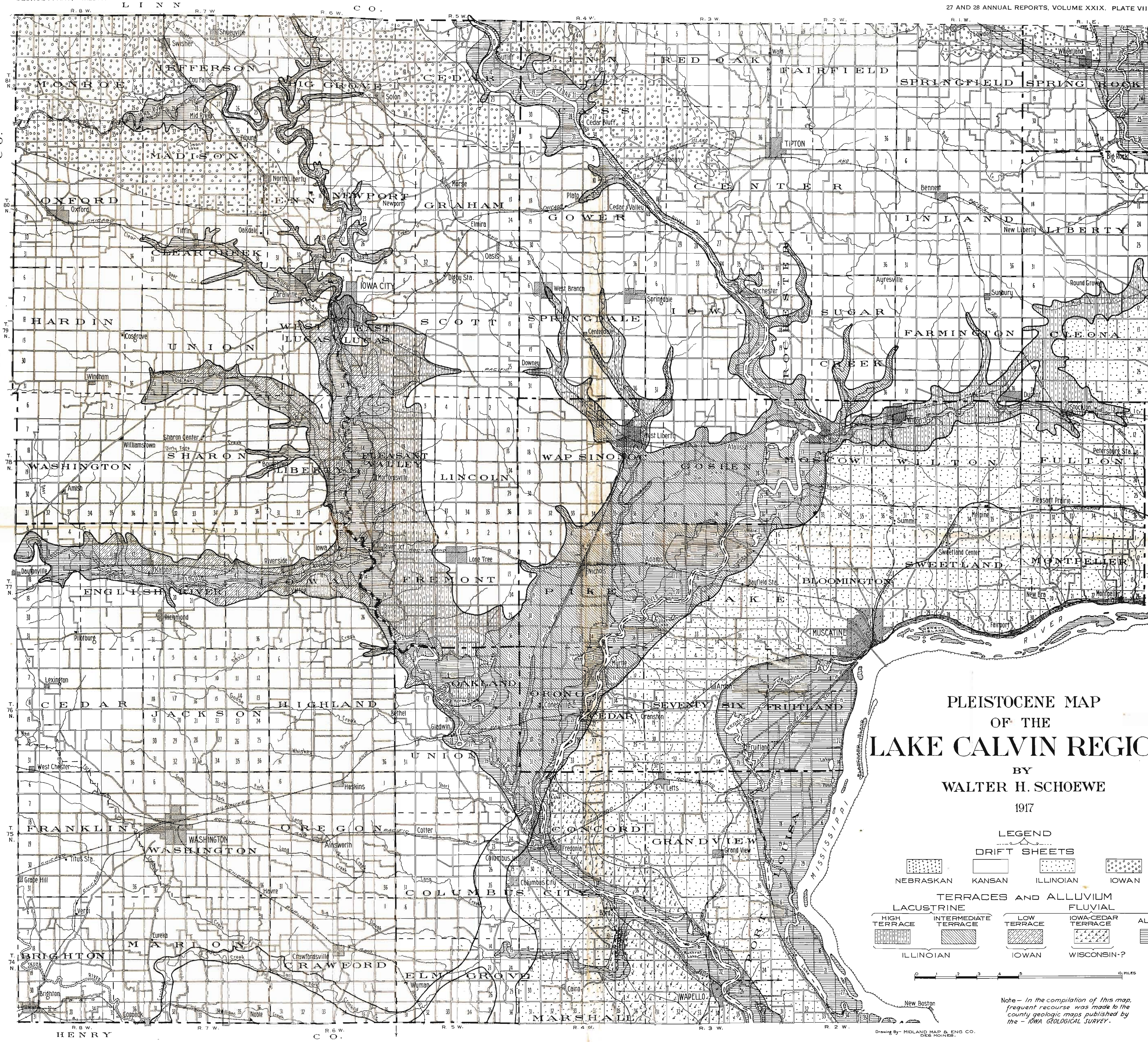


FIG. 8.—Diagram showing comparative areas of Muscatine county and the Lake Calvin basin. Cross-hatched portion represents the area of Lake Calvin.

the now dry lake floor, the Kansan has by far the greatest areal distribution. It includes, with the exception of two small areas, all of the region north and west of the lake basin. (See map showing the drift sheets in the Lake Calvin basin, Plate VIII.) The Iowan drift plain, which forms the two exceptions to the Kansan upland area just mentioned, borders the lake basin at its two northern extremities along Iowa and Cedar[146] rivers respectively. The more widespread Illinoian plain comprises the entire remaining area of the region south and east of the lake lowlands.

[146] The Iowan age of the drift plain bordering on the eastern side of Cedar river and known as the Tipton Lobe of the Iowan drift sheet, has recently been questioned. See "The Iowan Drift" by Wm. C. Alden and Morris M. Leighton, Iowa Geol. Survey, Vol. XXVI, p. 179, 1916.


PLEISTOCENE MAP
OF THE
LAKE CALVIN REGION
BY
WALTER H. SCHOEWE
1917
LEGEND
DRIFT SHEETS
NEBRASKAN
KANSAN
ILLINOIAN
IOWAN
TERRACES AND ALLUVIUM
LACUSTRINE
FLUVIAL
HIGH TERRACE
INTERMEDIATE TERRACE
LOW TERRACE
IOWA-CEDAR TERRACE
ALLUVIUM
ILLINOIAN
IOWAN
WISCONSIN-?
Note— In the compilation of this map, frequent recourse was made to the county geologic maps published by the - IOWA GEOLOGICAL SURVEY.
Drawing By - MIDLAND MAP & ENG CO. DES MOINES.
LINN CO.
IOWA CO.
SCOTT CO.
HENRY CO.
IOWA CITY
MUSCATINE
WASHINGTON
TIPTON
WAPELLO
MISSISSIPPI
RIVER

View in northeastern Washington county, Iowa, showing mature erosion of the Kansan drift plain. Relief 100 to 150 feet.

The Kansan Upland.

Topography.—The Kansan drift plain, which comprises by far the greater portion of the highland bordering the lake basin, consists of a maturely dissected upland (Plate IX) whose general elevation lies between 840 feet above sea level in the northern and western parts of the lake region and 740 feet near the borders of the lake basin. Originally it was a somewhat gently sloping flat plain, but its surface today is deeply incised by an intricate dendritic system of valleys. Topographically, the region presents many diversities. As one approaches the larger stream valleys from the interstream areas, a gradual and orderly change from the uneroded, flat original drift plain to a rolling and finally rugged and rough type of country makes itself manifest. The only extensive area of the initial uneroded upland surface lies south of the English river valley in Washington county. Here the topography is practically in its original, unaltered state and forms wide flat-topped interstream divides. The valleys which have been cut into its surface are characteristically broad bottomed, open shallow swales whose long gentle slopes merge imperceptibly into the upland. At places the surface is still so flat and poorly drained that tiling has to be employed. At various other places, which are located at considerable distances from the larger streams and where the effects of running water have been but slightly felt, remnants of the original Kansan surface may still be preserved as narrow divides of limited extent and crenulated margins. Such erosional remnants are met as one travels over the lower Muscatine road between Iowa City and Downey, in the region lying east and north-east of Iowa City and extending up to Cedar river, and on the west side of Iowa river between Iowa City and Old Mans creek. Away from the uneroded remnants of the original plain and nearer the master streams the surface of the upland is more indented by the numerous ramifications of the arborescent drainage system, the broad-bottomed open swales with long gentle slopes are constricted to narrower, steep-sided valleys, the relief is greater until finally at the borders of the upland the streams have thoroughly dissected the region. Here maximum ruggedness and relief prevail. This is the border country of the river-like extensions of the lake basin, north of Iowa City and the village of Rochester, along Iowa and Cedar rivers respectively. Here the surface has been deeply incised into a complex rugged region of spurs, buttresses and abrupt convex-sloped hills, which lie between sharply cut steep-sided ravines and valleys which

FIG. 9.—View of the incised valley in the Kansan upland in section 36, Elm Grove township, Louisa county.

have a relief of sixty to one hundred and sixty feet and long winding even-crested ridges. Where the drift topography has been modified by loess only to a slight extent, this ruggedness becomes less pronounced. Although it is all reduced to slopes, the country is less deeply dissected, the slopes are gentler and the valleys wider and more open. Such is the characteristic rolling or undulating Kansan upland between the valleys of Old Mans creek and English river and that portion of the drift plain lying to the east of Iowa river south of a line passing through Iowa City and Rochester.

A departure from the usual normal type of topography is seen in Louisa county immediately west of the limits of the Illinoian drift plain. Extending in a southerly direction from the Iowa river border of the upland just north of Columbus Junction and paralleling closely the edge of the Illinoian drift sheet is a definite wide and shallow sag from one and one-quarter to one and one-half miles wide and thirty to sixty feet deep. This shallow incised valley, which rises ninety to one hundred and twenty feet above the level of Iowa river and which lies at an elevation of about 700 feet above sea level, in the vicinity of Columbus Junction, is more pronounced the farther south it is traced. At places it is occupied by streams, whereas other portions of it are still uncut by drainage channels. The photograph (Fig. 9), taken in section 36 of Elm Grove township, shows that the incised valley is cut thirty-five to forty feet below the general upland and is one mile wide. This place practically marks the divide between the north and south flowing streams developed in the sag.

Attention was first called to this abandoned channel by Mr. Frank Leverett of the United States Geological Survey who traced its devious course to Fort Madison, Lee county.

The Illinoian Upland.

Topography.—The Illinoian upland comprises that portion of the lake region east and south of the lake basin or lowland which lies between Cedar river, Mud creek and Mississippi river. Separated from the lowlands to the west by a line of bluffs seventy to one hundred feet in height, the Illinoian surface lies at an average elevation of 720 feet above sea level. In contrast to the Kansan highland whose general surface slopes gently to the south or southwest, the Illinoian upland is inclined in all directions so that its surface is drained to the north, west, south and east. Except for that part of the region lying north of Muscatine the divide between the drainage lines lies closer to the eastern edge of the upland than to the western border. Because of this, the northward and westward flowing streams are the larger and occupy the shallower and more open type of valley. South from the latitude of Muscatine, the watershed has shifted entirely to the east and now follows the bluffs of Mississippi river and forms the eastern edge of the upland plain. Here its crest ranges in elevation from 750 to 770 feet in the north to 680 feet above sea level in the south, in the latitude of Wapello. North and west of Muscatine, the height of land between Mississippi and Cedar rivers lies about midway between the two streams. The highest part of the plain is on the divide between Mud creek and Mississippi river in section 18, Fulton township, two and one-half miles southeast of Durant. At this place an elevation of 800 to 820 feet above sea level is attained.

Due to its varying width and proximity to master drainage lines, the Illinoian upland presents many diversities. One of the most noteworthy topographic features of the drift plain is the fringe of sand dunes which follows the western border of the upland south of Mosquito creek in Moscow township to the vicinity of Columbus Junction. This sandy undulating fringe is made especially conspicuous because of its abrupt termination at the southern extremity of the lake basin at Columbus Junction. South of the Junction no trace of a sand dune marking the limit of the Illinoian plain is to be seen. The dune-covered area is, as a rule, less than half a mile wide. However, at places such as the region two to three miles north of Bayfield, the dune topography extends inland from the edge of the drift plain for a distance of one mile to two miles. The average height of the sand knolls and ridges is twenty feet, but some of them reach heights of forty to fifty feet at those places where the sand covers larger areas. Numerous ponds, as the one seen on the right hand side of the following photograph (Fig. 10), are hemmed in among the dunes.

In contrast to the Illinoian drift plain of Lee and Scott counties, which is characterized by extensive areas of the original upland in the form of broad tabular interstream divides, the surface of the drift sheet in the lake region is more or less cut up into an undulating type of topography. Flat remnants of the uneroded surface are found only in that part of the drift plain south of Iowa-Cedar river and in the country forming the watershed between Mud creek, Cedar and Mississippi rivers north of Muscatine. In all directions from these flattish remnants or interstream areas the country is more and more cut up. The upper parts of these erosion lines are wide open swales or sags which, closer to the master streams, Mississippi and Cedar rivers, develop into deeper valleys until, finally, within a few miles of the main drainage lines, the whole topography is etched into a system of hills and valleys by the numerous ramifications of the dendritic stream courses. Thus everywhere along the eastern and southern border of the upland the bluffs of Mississippi river are cut into by young streams whose heads are 100 to 150 feet below the uplands. South from the latitude of Muscatine, in townships Seventy-Six of Muscatine county and Grand View and Port

FIG. 10.—Characteristic sand dune topography on the Illinoian border within the lake basin.

Louisa in Louisa county, the young valleys or ravines are very steep-sided, narrow and short and extend back into the upland on the average less than one mile. The streams occupying the valleys have high gradients. Because of the position of the divide relative to the master streams, the northward and westward flowing streams, as a rule, flow in more open and wider valleys than those pursuing the southerly and easterly courses. Such are the valleys especially in the northern tier of townships in Muscatine county. South of Mosquito creek, in Moscow township, Muscatine county, the valleys form the conspicuous feature of the landscape. They range from sixty to seventy feet in depth, and, together with the numerous sand dunes dotting the surface, present an unusual type of topography, one which is both constructive and destructive and which is particularly characteristic of this portion of the Illinoian drift plain.

The continuity of the Illinoian plain is broken in the southern part of the lake region at two places. At Columbus Junction, the northwest-southeast trending valley of Iowa-Cedar rivers divides the drift plain into two uplands which are separated by a valley three to five and one-half miles wide. The northfacing end of the upland south of the gap consists of steep undissected bluffs which rise one hundred feet or more above the valley floor. The bluffs on the opposite side of the valley range in height from forty-five to eighty feet, are gentler and some of them are fringed by a line of low sand dunes. The southern portion of the upland is redivided into north and south sections by the valley of Long creek. This valley is four and one-half miles south of Columbus Junction and is one-quarter to one-half mile wide and seventy to eighty feet deep. South of Long creek the western edge of the upland is marked by two parallel ridges which were considered by Udden[147] to be terminal moraines. These ridges, which are about one mile wide and which rise as high as fifty feet above the general surrounding level, are separated by a sag or depression one-half to one mile wide.

The Iowan Drift Plain.

Topography.—North Liberty Lobe.—The Iowan drift sheet forms a lobate upland area in the northern part of the lake region. The largest of the five tongue-like extensions of this drift sheet,[148] named the North Liberty Lobe by Calvin, enters the lake region in the northwestern part of Monroe township, Johnson county, and extends southeastward across the Iowa

147 Iowa Geol. Survey, Vol. XI, pp. 63 and 107, 1901.

148 The lobate character of the Iowan drift plain, with the exception of the North Liberty Lobe, has recently been questioned. See "The Iowan Drift" by Wm. C. Alden and Morris M. Leighton, Iowa Geol. Survey, Vol. XXVI, pp. 177, 179, 180, 1917.

View showing the flat surface of the North Liberty plain.

View showing the erosional topography of the Kansan. Taken near the border of the North Liberty plain.

river valley, the uppermost extremity of the lake basin, to a point one and one-half miles south of North Liberty. The topography of this area is in sharp contrast to the surrounding rough erosional Kansan plain, from which it is separated in the southern part by a fringe of rounded hills, termed "paha" by McGee. (Compare Plates X and XI.) Its surface is gently undulating and is scarcely scarred by the indentations of drainage lines. "Northwest of the village of North Liberty, just beyond the reaches of Pardieu creek, the surface is typically of the 'swell and swale' type. Farther northwest is a topography of unrelated elevations and depressions which has a relief of not more than twenty feet and slopes not greater than twelve degrees. One depression is occupied by a small pond of water while the others are of a slough character. Many undrained depressions exist in the northeast quarter of the plain, notable among which is Swan lake."[149] That portion of the Iowan plain lying south of Iowa river is practically unaffected by drainage except near its borders. The "somewhat higher and more billowy"[150] north lying portion is more highly cut up by young valleys and ravines whose depth where they join the Iowa river valley differs from eighty to more than 120 feet.

Shueyville Lobe.—A very much smaller extension of the Iowan plain, with similar surface characteristics, lies east of the North Liberty Lobe, to which it is connected. This plain is known as the Shueyville Lobe.

A question has recently been raised by Alden and Leighton as to whether the remaining tracts of so-called Iowan drift in the lake region, known respectively from west to east as the Solon, Tipton and Clinton Lobes, really belong to the Iowan drift plain.[151]

Solon Lobe.—The Solon Lobe as described by Calvin[152] "occupies a low plain when compared with adjacent loess-covered

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149 Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and East of Iowa City in Johnson county: Iowa Geol. Survey, Vol. XXV (1914), p. 128, 1916.

150 Calvin, Samuel, Geology of Johnson County: Iowa Geol. Survey, Vol. VII, p. 42, 1897.

151 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift, Iowa Geol. Survey, Vol. XXVI, pp. 177, 179, 180, 1917.

152 Iowa Geol. Survey, Vol. VII, p. 41, 1897.

areas which are in general highlands of moderate elevation." Its surface is smooth. Like the southern part of the North Liberty plain, the Solon lowland area is circumscribed by a belt of paha. Alden and Leighton in their thesis "The Iowan Drift", remarking on the Solon Lobe, state, "The writers have no definite evidence of the presence of Iowan drift in this area."[153]

Tipton Lobe.—The Tipton Lobe lies on the east side of Cedar river which it parallels southward within a mile to a mile and a half of Cedar Valley. The surface of this plain is divided by Baldwin creek into two topographically unlike parts. That part of the plain to the north and west of the creek "presents an exception to the usual undissected character of the Iowan surface"[154] and is in all respects similar to any of the Kansan upland topography bordering Cedar river. The remaining parts of the Tipton Lobe "compare with sufficient closeness to the normal Iowan drift plain."[155] Alden and Leighton "after considering everything, and especially the erosional character of the topography surrounding this area"[156] doubt if the Iowan ice ever covered the tract known as the Tipton Lobe.

Clinton Lobe.—Similarly, the Iowan age of the Clinton Lobe, which occupies but a very small area on both sides of Wapsipinicon river in the lake region, has been questioned by these same writers.[157]

Upland Remnants.

Moscow Remnant.—Two small isolated remnants of the Kansan upland occur within the lake basin. Of these, the larger and more conspicuous has an area of about one and one-half square miles and occupies practically all of section 7 and parts of sections 6, 8, 17, and 18 of Moscow township, as well as small portions of sections 12 and 13 of Goshen township, in Muscatine county. This island-like highland is separated from the main upland to the northwest by a distance of half a mile and rises

153 Iowa Geol. Survey, Vol. XXVI, p. 180, 1917.
154 Norton, Wm. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 372, 1901.
155 Idem, p. 372.
156 Iowa Geol. Survey, Vol. XXVI, p. 179, 1917.
157 Idem, pp. 177 and 179.

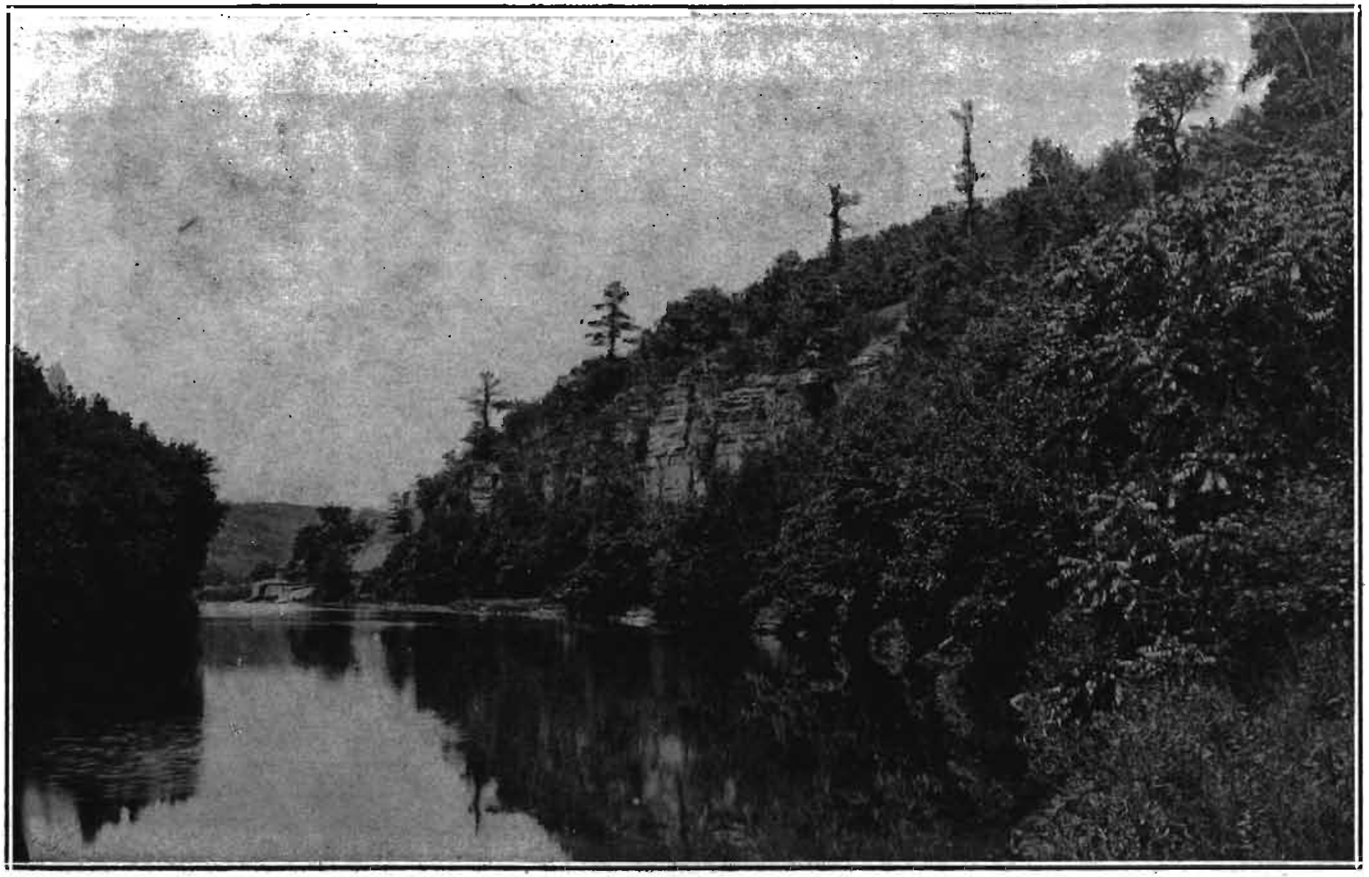
on the average seventy-five feet above the level surface of the surrounding plain, that is, the intermediate terrace. Its summit reaches an elevation of 760 feet above sea level at the school-house in section 7. This is 110 feet higher than the road at the base of the upland in section 8, about three-fourths of a mile directly east, and marks the highest point within the lake basin. The bluff-line on the north and east is cut into the Devonian limestone and is therefore very well defined. Where the slopes are not broken by quarries they have an average inclination of about seventeen degrees. Toward the south and especially toward the southwest, the border of the remnant is less conspicuous, due to the numerous sand dunes, and merges more gradually into the surrounding lowland. Sand dunes crown the summit.

Iowa City Remnant.—The Iowa City remnant of the Kansan upland is less well outlined than the one in the vicinity of Moscow. It extends southward as an isolated ridge from what is now Iowa Avenue in Iowa City as far as Kirkwood Avenue and its top is followed by the well-named Summit street. From Kirkwood Avenue the island spreads out in a general east-west direction, and has the appearance of a large railroad spike. Approximately one square mile is occupied by the remnant, whose maximum length and width are one mile and one-half mile respectively. It is separated from the main upland by the valley of Ralston creek, which is half a mile wide. The surface of the remnant is loess-covered and in Iowa City it is now modified by the works of man. The borders of the highland rise five to forty-five feet above the surrounding country and are well marked, especially as seen from the northeast, south and southwest.

The Bluff Line.

General.—Except for the river-like extension of the lake basin, the bluff line is conspicuous for two outstanding features: namely, its relative straightness and its smoothly curving or rounded outline at places of indention. Even in the narrower arms of the basin, there is indication of these characteristic features of the main lake border, rather than of the sharper sinuousities of meander scars. The bluffs are mainly cut in the unconsolidated drift materials of the various till sheets bordering the lake basin. Bedrock forms part of the bluffs in the western and southwestern end of the English river branch of the basin, along Iowa and Cedar rivers north of Iowa City and Moscow respectively, in the north and east faces of the bluffs of the island-like upland one mile west of Moscow and in a portion of the west facing slope of the isolated upland area in the southern part of Iowa City. The rock consists chiefly of Devonian and Mississippian limestone, although sandstone and shale of Pennsylvanian age form the bluffs at a few places. For a description and location of these rock formations the reader is referred to chapter III. Where the bluffs are cut into the country-rock they are exceptionally steep and even precipitous. (See Plate XII.)

Illinoian Bluffs.—In spite of the meandering of Cedar river and the numerous places through which the streams of the upland descend to the lowlands, the eastern margin of the lake basin in Muscatine county is remarkable for its straightness. Starting from the southeast corner of section 32, Cedar township, the bluff, composed largely of Illinoian till, sand and loess, trends northeastward with a striking directness as far as the northcentral part of section 6 of Bloomington township. From here the bluffs swing in a smooth gentle curve northeastward to the southcentral part of section 28, Moscow township, continuing thence directly northward for two and one-half miles to the valley of Mud creek. From this place the line of bluffs follows in a more irregular outline the valley of Mud creek. The border of the lake basin just described forms the western margin of the Illinoian upland. Along practically its entire northeastward course of twenty-three miles, its top is covered by the rolling sand dunes previously described. The slopes are steep and range in height from one hundred feet or more in the south to seventy-five feet in the north. The base of the bluff is sharply defined from both the terrace and the flood plain, which abut against it. Along the margin of the lake basin eastward in the valley of Mud creek, the line of demarcation between upland and lowland is less pronounced than in the lake basin pro-



View showing the steep and rocky bluffs of the Lake Calvin basin along the Cedar river extension north of Moscow.

per. Nevertheless, a line of division can be drawn. On the south side of the valley, the lowland merges into the uplands in a fairly smooth curve. The north line of the bluffs, however, is more sharply defined, rising at places twenty-five to thirty feet above the terrace in the valley. In the small ramifications of the Wilton Valley arm of the lake basin, the bluff line is, as a rule, more or less indefinite and not more than fifteen feet high.

Bluffs of the finger-like extensions of the lake basin.—The bluffs are very pronounced and steep in the large finger-like ex-

FIG. 11.—View of the northern line of bluffs in section 18, Wapsinonoc township, Muscatine county.

tensions of the lake basin, as along Cedar river north of Moscow, in the Wapsinonoc valley north of West Liberty, up the valleys of English river and Old Mans creek and along Iowa river north of Iowa City. This is especially true where these bluffs are cut into solid rock. At many places the bluffs reach a height of seventy to eighty feet, although a rise of thirty to fifty feet[158] above the level of the river is more common.

Bluffs between West Liberty and Atalissa.—The northern bluff line between West Liberty and Atalissa in Muscatine county, although it is less abrupt and lower than the bluffs to the east or west, is nevertheless at most places very distinct

[158] Leighton, Morris M., The Pleistocene History of Iowa River Valley, North and West of Iowa City in Johnson County: Iowa Geol. Survey, Vol. XXV, p. 157, 1914.

and sharply set off from the lowland to the south, called by Udden the West Liberty Plain.[159] (See Fig. 11.) The heights of these bluffs range from forty to fifty-five feet. As the map (Plate VIII) shows, this border is also somewhat more sinuous than the one which forms the western margin of the Illinoian upland or the line of contact between the Kansan drift plain and the lowland, south of West Liberty. Immediately west of Atalissa is a rounded peninsula-like projection of the bluff line rising forty to fifty feet above the surrounding level plain.

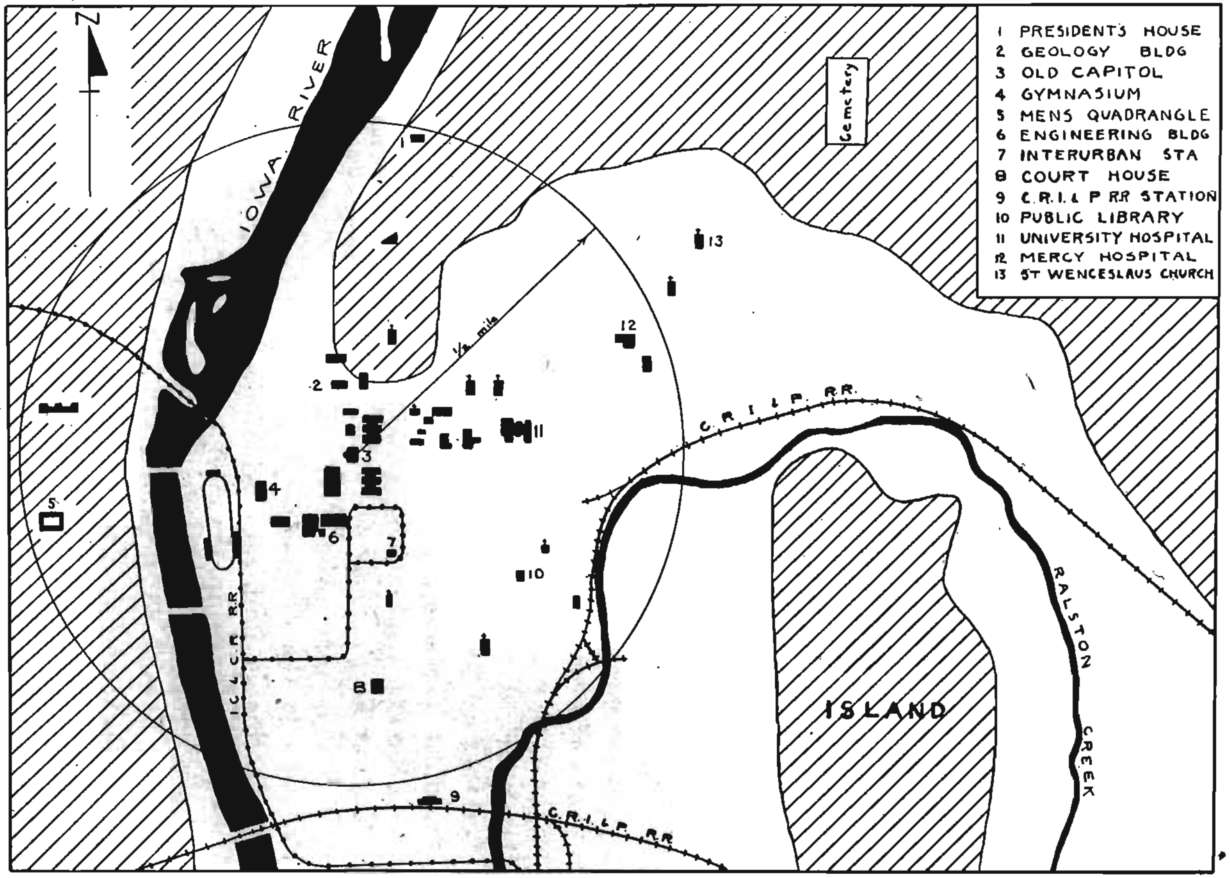
Kansan Bluffs in western Muscatine county.—As viewed from the West Liberty Plain the western bluff line extending southwestward from West Liberty in a relatively straight or gently rounded outline, has, especially in the vicinity of Nichols, an almost even sky line. The bluffs rise abruptly from the lowland and range in height from less than sixty-five feet two miles south of Nichols to ninety feet in section 26, Wapsinonoc township, and to thirty-five feet in the vicinity of West Liberty.

Kansan Bluffs in eastern Johnson county.—From the northwest corner of section 30, Pike township, Muscatine county, the bluffs continue their southwest course and extend into Johnson county for a little over half a mile to the southeast part of section 25, Fremont township. In this distance they maintain their sharp outline, but rise to progressively decreasing heights above the lowland. They are broken by a gap which extends to the corner of sections 23, 24, 25, and 26, but beyond this break the bluff line trends in a smoothly rounded curve to the southwest corner of section 27, although it is much less conspicuous and definite. Beyond the southwest corner of section 27, the bluffs again show their characteristic features, rise sharply forty feet above the lowland to the west and continue in a northerly direction practically to the southern limits of the village of Lone Tree. North of the village as far as section 31, Scott township, the bluff line presents much less definiteness of outline and also is lower,

159 Iowa Geol. Survey, Vol. IX, p. 257, 1899.

but maintains its relative straightness. The inconspicuousness of the border between lowland and upland is due in large measure to the numerous rolling tracts of dunes which mask the sharpness of the contact line. These dunes in many places cause a blending of the upland into the lowland and only from some distance on the lowland can the line of demarcation be recognized. Beyond section 31, Scott township, the line of bluffs shows its prominent features again, being easily traceable at first to the east and then to the west and north up to Iowa City. A very fine view of the bluffs, as well as of the lowlands, is to be had just east of Iowa City where, in sections 13 and 18 of East Lucas and Scott townships respectively, the old Muscatine road closely parallels on the north side the line of bluffs for over two miles. Even in Iowa City, in spite of the evenly paved streets, the walks and the buildings, a sharp break in the topography is in evidence and can be traced fairly distinctly throughout the city. (See Plate XIII.) Thus while walking up Dubuque street northward from the Methodist church, one can easily follow on the left hand side a sharp rise which separates the higher from the lower parts of the city. Just about at the intersection of Dubuque and Davenport streets, this topographic break swings off to the northeast as far as Dodge street, whence it turns gently southeast until it reaches the Upper or Old Muscatine road from which the fine view just referred to is to be had.

Kansan Bluffs south of Iowa City.—South of Iowa City the bluff line is very prominent and can be followed with ease. Its slope to the lowland or terrace is definite and steep and its sky line is uniform. At Indian Lookout, in section 34, West Lucas township, the bluffs rise 120 feet above the terrace, but are gradually lower in the direction of Iowa Junction where in section 10, Iowa township, Washington county, they have a height of only sixty-six feet. In the angle between Iowa and English rivers, the slope bordering the flat forms a very broad almost invisible curve without any suggestion of a projecting divide between the two streams. This same type of slope which is found also in the southern angle between the



MAP SHOWING LAKE CALVIN AT IOWA CITY

two streams, may be said to be characteristic of the bluff line between places of indentation.

From Iowa Junction the bluff line extends in a relatively direct line with a southeast trend to Columbus Junction in Louisa county. Between these two points the bluffs are about 140 feet high and for the most part are steep because of the lateral planation of Iowa river at their base.

Terraces.

General description.—At least three sets of terraces, a high set, an intermediate set and a lower one, occur in the Lake Calvin basin. Of these, the intermediate terrace, designated by Udden in his Muscatine county report as the West Liberty Plain,[160] is the most extensive and continuous. It comprises practically the entire higher lowland areas in Muscatine county and extends southward as far as Columbus Junction, Louisa county, occupying the higher land area in the triangle made by the junction of Iowa and Cedar rivers.

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

The lower terrace is restricted to the narrow river-like extensions and to the western branch of the "V" of the lake basin. This terrace, with one exception, is not continuous but occurs in narrow linear remnants south of Iowa City and as "mere remnants at the bends of the stream"[161] north of Iowa City and possibly north of Moscow along Cedar river.

160 Iowa Geol. Survey, Vol. IX, p. 257, 1899.

161 Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI, p. 136, 1916.

THE INTERMEDIATE TERRACE.[162]

TOPOGRAPHIC FEATURES.

Area.—The intermediate terrace forms the major portion of the lowland in Muscatine and Louisa counties which was designated by Udden as the West Liberty Plain. The writer's investigation has led him to the conclusion, however, that the West Liberty Plain as described by Udden really consists of two lowlands or terraces, one designated in this report as the upper or high terrace and the lower of the two as the intermediate. The "two narrow extensions"[163] of Udden's West Liberty Plain the "one to the northwest, consisting of the bottom lands along Wapsinonoc, and another to the northeast, a rather ill-defined lowland drained by Mud creek"[163] form the two terrace remnants corresponding to the high terrace in the Iowa river arm of the basin. Furthermore the western portion of "the northernmost expansion"[164] of the Iowa river lowlands in Louisa county, which lies west of Prairie creek in Oakland township and which "constitutes the south end of the West Liberty Plain"[164] really forms the southern extremity of the upper or high terrace along Iowa river.

Topography.—The lowland or terrace, which is sharply set off from the surrounding drift uplands by a line of steep bluffs previously described, is traversed from north to south by Cedar river which has incised its valley twenty to forty feet below the general surface of the terrace. The vast plain is remarkable for its uniform width. For a distance of fourteen miles out of the twenty-two and one-half miles of its length, the terrace maintains an average width of four and three-fourths miles. On the west side of Cedar river, the intermediate terrace is continuous for its entire length from West Liberty or Atalissa in the north to the southeastern corner of section 18, Concord township, Louisa county, in the south, whereas to the east of the river, the terrace occurs in

162 In view of the fact that Udden's West Liberty Plain forms the major part of the intermediate plain and since a detailed description of it has been given in his Muscatine county report in connection with Lake Calvin and is therefore best known it was deemed advisable to consider this terrace first.

163 Iowa Geol. Survey, Vol. IX, p. 257, 1899.

164 Iowa Geol. Survey, Vol. XI, p. 61, 1901.

at least nine remnants. The largest of these remnants is the one on which the village of Moscow is situated and which can be traced for a distance of seven miles. All of the other remnants are very much smaller and have a width which in few places exceeds one mile.

Although without slope which is apparent to the eye, the terrace has a very gentle dip to the south. The surface of the plain lies approximately 660 feet above sea level in the northern extremity at West Liberty and slopes gently to the southern end of the terrace in Louisa county, eighteen miles distant. Here it has an elevation of 615 feet above sea level. Topographically, the intermediate terrace is still in its early youth for its surface is scarcely scarred by stream erosion. With the exception of the valley of Wapsinonoc creek, the few water courses developed on the terrace surface are more in the form of ditches five to eighteen feet deep and a few feet to a rod or two wide rather than well developed young valleys. The larger streams such as Wapsinonoc, Honey and Prairie creeks have developed larger sags which have on the average a width of one-fourth mile and a depth of twenty feet. To insure proper run-off on the plain, numerous drainage ditches have been dug and resort has been had to tiling. Although it is practically flat, the surface of the plain is not without some relief. Scattered over the entire area, but especially in the vicinity of the Cedar, there are stretches of low lying mounds or dunes of sand. Some of these are in the form of long winding and irregular ridges varying in height from ten to thirty-five feet. Their position on the plain is indicated on the map of Muscatine county published by the United States Bureau of Soils by the symbol, Ks, Knox fine sand.[165] A series of sand dunes in sections 12 and 13 of Goshen township and in section 7 of Moscow township, Muscatine county, occurs not only on the terrace but also covers the southeastern flank and a large part of the top of the island-like upland near Moscow which has previously been de-

165 U. S. Department of Agriculture, Bureau of Soils, Soil Survey of Muscatine County, Iowa, Soil Map, 1916.

scribed under the heading Upland Remnants. The dunes here average about twenty feet in height.

Bowlders on the terrace.—At several places large bowlders lie scattered over the surface, as well as along the base of the escarpment of the terrace. At the base of this escarpment in the northeast corner of section 7, Concord township, Louisa county, fifty or more large granite bowlders weighing perhaps on the average a ton each were noted. At this locality, Cedar river flows at the edge of the terrace. It is also worthy of remark in this connection that these bowlders are but half a mile west of the Illinoian bluffs. In the central part of section 34, Pike township, Muscatine county, a limestone bowlder lies on the surface of the terrace and in section 3 of the same township many bowlders are scattered on the escarpment slope as well as near its edge, high above the river or flood plain level. In the same section in the northwest corner of the northeast quarter along the escarpment slope and at its base are several granite and greenstone bowlders which have dimensions of one by one foot. These bowlders are two miles east of the Illinoian upland. Udden also mentions the finding of bowlders "near the south line of section 8, in Wilton township . . . and one near the center of the west line in section 2, in Moscow"[166] in Muscatine county.

Relation to other topographic features.—The intermediate terrace is sharply set off from the various drift uplands by a steep and well defined line of bluffs already described. In Fremont and Oakland townships of Johnson and Louisa counties respectively, the high and intermediate terraces are separated by a well outlined although somewhat sinuous escarpment. The surface of the terrace at the line of contact in Oakland township, especially in the lower halves of sections 3 and 10, is covered with dunes. Among the dune ridges, as in the northwest quarter of the southeast quarter of section 3, there are undrained depressions containing water. At the intersection of the road between sections 2 and 3 by the east and west road passing through the two sections, the upper

166 Iowa Geol. Survey, Vol. IX, p. 354, 1899.

terrace is forty feet above the intermediate terrace. The line of separation between the high and lower terraces in the vicinity of West Liberty is equally well outlined.

In sections 12, 13, 14, 23 and 27 of Oakland township, Louisa county, the intermediate terrace is separated from the high terrace by a large marshy slough or lowland about one mile wide. The terrace escarpment is sharply defined, is relatively free from irregularities and has an average height of thirty feet. Elsewhere the terrace is separated from the bottom lands of Iowa and Cedar rivers by a sinuous escarpment whose height ranges from twenty feet in the south to almost fifty feet in the north.

MATERIALS AND STRUCTURE OF THE INTERMEDIATE TERRACE.

General.—The study of the materials and structure of the intermediate terrace is practically limited to a score of exposures most of which are in the west escarpment of the terrace in section 13, Goshen township, Muscatine county. This lack of exposures is due to the extreme youthfulness of the topography and the slight relief of the region. Experience shows that in a region such as this, where the materials are fine unconsolidated sand, silts and gravels, where the wells are of the shallow and dug type, and where there is a vast amount of changing of ownership of the land, very little stress can be laid on well records gained from the people of the community. Most of the wells reported were about thirty feet deep and the material penetrated consisted principally of sand, although gravel and clay were at times mentioned. The deepest well in the area of the intermediate terrace is at Nichols and is recorded to have penetrated at least 250 feet[167] of unconsolidated material. The surface materials consist of fine yellowish to brownish or drab-colored loesslike silt and sands, the latter forming the sandy and dune areas previously described. Occasionally, a few scattered bowlders are found dotting the terrace surface.

[167] Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 355, 1899. Also U. S. Department of Agriculture, Bureau of Soils, Soil Survey of Muscatine County, Iowa, p. 23, 1916.

Material and Structure.—Practically the only clew as to the nature of the materials composing the intermediate terrace is to be found in the terrace escarpments facing Cedar river. Although the east facing escarpment of the modern valley of Cedar river has a length of thirty-five miles, cuts showing the materials of the terrace are limited practically to the northernmost five or six miles. Out of the nine outcrops exposed within these five or six miles, five occur within a distance of three-fourths of a mile in section 13 of Goshen township, Muscatine county. As far as could be ascertained from the few exposures seen, it appears that the terrace materials in the northern part of the plain are finer and less disturbed than those farther south. The following section in the western escarpment wall near the south line of section 8, Goshen township, Muscatine county, shows that the material is all finely stratified, not disturbed, and consists of fine-grained sand and some clay.

TERRACE MATERIALS, SECTION 8, GOSHEN TOWNSHIP. MUSCATINE COUNTY.

		FEET	INCHES
A.	Loesslike clay	2	
B.	White, fine-grained stratified sand containing many small pebbles or grains, mostly of chert or quartz	2	
C.	Chocolate-colored fine-grained sand		3
D.	Iron oxide nodule layer		¼
E.	Fine laminated pebbleless clay or silt	1	
F.	White stratified fine-grained sand, containing some clay	2	
G.	Fine laminated fine-grained sand, laminæ one-fourth of an inch thick and of various colors as chocolate, brown, yellowish and white, exposed	2	
H.	Slump	25	

In the five exposures in section 13 of the same township, one mile south of the cut just described, the materials are similar to those mentioned. The sand is fine to medium-grained and has a dominant white color. The stratification is essentially horizontal and thin. Some cross-bedding and contortion of the beds occurs as is indicated by the lower bed No. H shown in the following diagram (Fig 12) and section.

		Feet	Inches
A.	Brown sandy soil	1	6
B.	Brown medium-grained sand, poorly stratified	3	10
C.	Yellow, light colored medium-grained sand, stratified	1½-2	
D.	Hard dark brownish medium-grained very resistant sand	1	
E.	Medium to coarse-grained light brown sand, cross-bedded		6
F.	Fine light yellow stratified sand		6
G.	Resistant brown sand, medium grained	1/3-2	
H.	Thinly bedded layers of brown and light yellow sand. Contorted layers an inch thick, exposed	2-3	
I.	Slump	30	

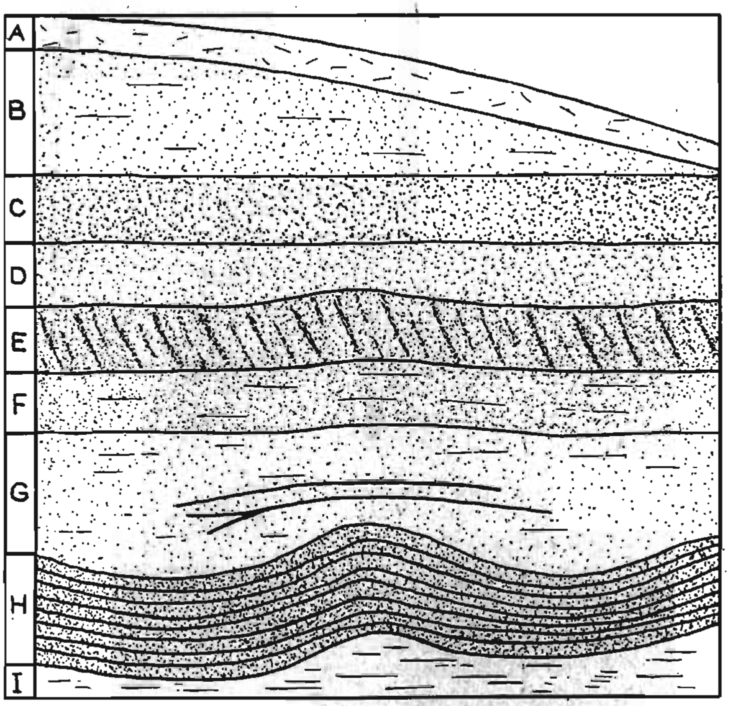


FIG. 12.—Diagram of exposure in the west terrace escarpment, southwest corner of section 13, Goshen township, Muscatine county. See the section above.

An idea of the prevailing fineness of the material may be had from the following photograph taken in the southeast corner of section 13, Goshen township.

In all of the exposures so far indicated, the material described forms the upper portion of the cuts, the lower half being hidden because of the heavy slump. However, on the opposite bank of the river east of the outcrops in section 13, in a gully four to five feet deep, in section 16, Moscow township, the sand is brownish and fairly coarse. Besides the sand, a gravel bed four feet thick and containing cherts, quartzites and other igneous rocks, is in evidence. The gravel is of low textural range and the diameter of the larger pieces does not exceed two inches. In elevation this gravel bed occupies a position corresponding to the lower five feet of the above

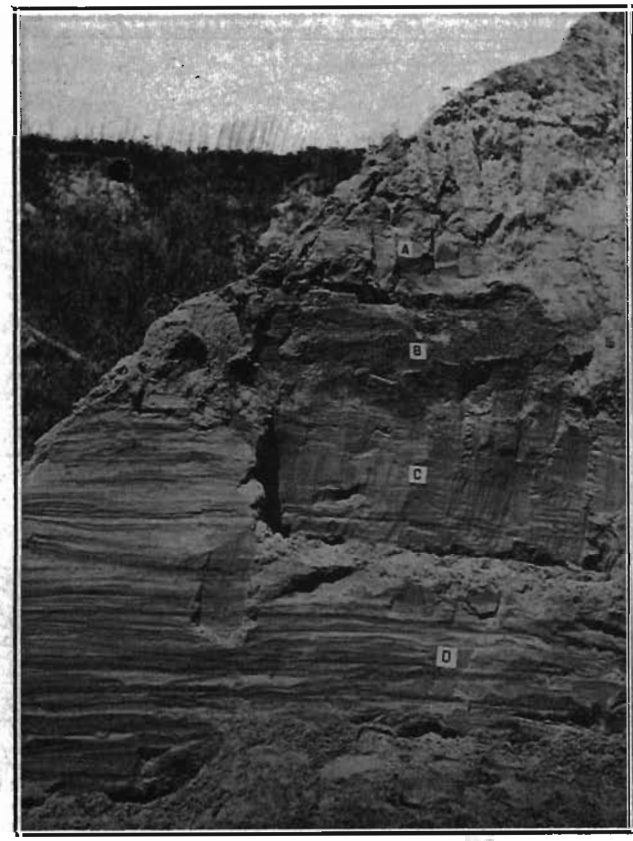


FIG. 13.—View of terrace material showing the fineness of the deposit.

described exposures in which that part is hidden from view by slump material. This great difference in the texture and color of the deposits as seen in the exposures on the west and east sides of Cedar river suggests that the two terraces may not be of the same age. This view is substantiated if one accepts the opinion of Udden[168] that the terrace on which Moscow is situated is younger than his West Liberty Plain. On comparing the elevation of the terraces at Moscow and on the west side of the river, it is found that there is a difference of four feet in elevation. The terrace at Moscow lies 654 feet above sea level and at Atalissa, five miles farther to the west,

FIG. 14.—View of the highly cross-bedded sands in the terrace in section 26, Goshen township, Muscatine county.

the elevation is 658 feet. This closeness of elevation suggests to the writer that there is but one terrace. Furthermore, Udden mentions in connection with his discussion on Lake Calvin "riffles of bowlders" in the bed of the river "at the old ford in section 36 in Goshen Township."[169] Also "On section 32, in Orono township, the river cuts into the gravel on the

168 Iowa Geol. Survey, Vol. IX, p. 361, 1899.
169 Iowa Geol. Survey, Vol. IX, p. 355, 1899.

plain bed."[170] Thus it appears that the base of the intermediate terrace is composed of coarser and more gravelly deposits than is the upper part.

The next exposure of terrace material south of the cuts in section 13, on the west side of the river, is in section 26 of the same township. Here, as in the other sections, the sand is prevailingly white and its stratification is on the whole very fine. Cross-bedding, lenses and unstratified thin sandy clay layers are in evidence. The cross-bedding dips to the east with an angle of about twenty-three degrees. See the preceding photograph. In this highly cross-bedded sand there are numerous thin layers of pebbles, the largest of which have a diameter under one inch. (Fig. 14.) In the exposure, a section of which follows, the uppermost crossbedded sand, No. D, shows more irregularity in its structure than the lower bed, No. G. Compare figures 14 and 15.

TERRACE MATERIAL, SECTION 26, GOSHEN TOWNSHIP. MUSCATINE COUNTY.

		Feet	Inches
A.	Very fine silty soil, in places peaty, appearances of indefinite stratification	2	
B.	Pebbleless leached sticky clay, the upper one foot of which is of a chocolate color and grades downward into an ash-colored clay. At places the ashy clay grades down into an extremely fine-grained silt or sand which shows cross-bedding. Stratification extremely fine. Contact between this and underlying bed irregular	5-7	
C.	Whitish fine-grained stratified sand with some brownish interbedded layers. Stratification practically horizontal and wavy, at places, upper half is finely cross-bedded	1-3	
D.	A whitish and iron stained sand showing both highly cross-bedded and lens type of structure. Some lenses consist of a very fine clay or silt. Sand fine to coarse-grained, with many thin interbedded pebble layers	2-3	
E.	Chocolate-colored clay or silt, extremely fine and full of moisture		1.5
F.	Dark gray clay or silt, similar to E		1.5
G.	Whitish and iron stained cross-bedded sand, dipping east with an angle of 23 degrees. Sand full of thin coarse pebble layers	3	
H.	Whitish horizontally bedded sand with numerous small pebble layers, stratification fine; exposed	2-3	
I.	Slump material		

Between the cross-bedded divisions, D and G, there are two layers of an extremely fine clay or silt containing much moisture. The total thickness of this clayey material is three

170 Idem, p. 355.

inches. Overlying the stratified sands and separated from them by an irregular line of contact or erosional unconformity is a pebbleless leached sticky ash-colored clay which at places grades down into an extremely fine-graded silt or sand

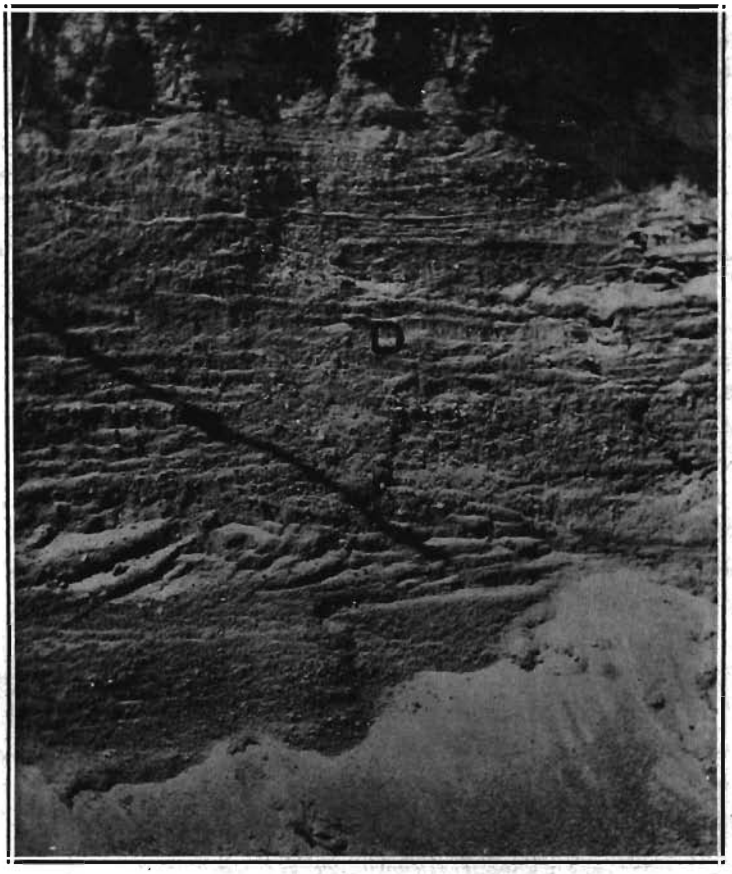


FIG. 15.—View of the irregular stratification of bed D in the same exposure as shown in figure 14.

which is very finely stratified and cross-bedded. This clayey deposit is presumably loess.

Other exposures showing the nature of the intermediate terrace deposit were seen on both banks of the recent Cedar valley as follows: (1) in sections 10 and 2 of Orono and Cedar townships respectively: (2) two and one-half miles northeast of Conesville and (3) in sections 13 and 2 of Oakland township.

in Louisa county. In sections 10 and 2 of Orono and Cedar townships the material consists of a fine to medium-grained brown sand containing numerous pebbles of low textural range. In section 2 no stratification is visible, whereas in section 10 the sands show cross-bedding. The deposit in the escarpment facing Prairie creek slough in the northwest corner of section 13, Oakland township, consists of very fine silt one-half a foot thick, overlying roughly stratified, brownish to red colored, fine-grained sand. Several other exposures which were visited reveal sands and structures which are similar to those described.

On page 361 of the Muscatine county report,[171] Udden states that "At Moscow the town is situated on a terrace which appears more recent than the West Liberty Plain. East of the railroad depot an excavation in this terrace, twenty feet deep, shows a structureless, yellowish surface sand two feet deep, resting on a white or gray sand rather free from gravel." As previously indicated, the writer is of the opinion that this terrace is a part of the intermediate terrace. If we consider the elevations, we will find that the terrace at Moscow is 654 feet above sea level and the intermediate plain at Atalissa, which is five miles to the west, is 658 feet above sea level. The material described by Udden does not differ essentially from that of the intermediate terrace. As the terrace is traced northward, it is found to be dune-covered, and on the west side of the river in section 26, Iowa township, Cedar county, the twelve foot exposure of extremely fine white stratified sand is overlain by a deposit of loess five to eight feet thick. Evidence of quiet water conditions is seen also in a terrace cut along a creek tributary to the Cedar in the southwest corner of section 22 of Iowa township. Practically all of the material is a fine stratified silt. The section is as follows:

TERRACE MATERIAL, SOUTHWEST CORNER, SECTION 22, IOWA TOWNSHIP, CEDAR COUNTY.

		Feet
A.	Brownish pebbleless loesslike clay	5
B.	Brownish, ash-colored silt or loess, extremely hard to penetrate. Iron mottled and containing pipe stems	5

171 Iowa Geol. Survey, Vol. IX, 1899.

		Feet
C.	Finely laminated ash-colored silt, iron stained layers	1-2
D.	Fine almost fatty laminated brown silt, interbedded with an ashy silt	1-2
E.	Ash-colored silt or clay, exposed to water level	3

Alden and Leighton in their report "The Iowan Drift"[172] indicate that some of the deposits of the terrace along Cedar river south of Rochester "may have resulted from slack-water during the Illinoian stage."[173]

THE HIGH TERRACE.

TOPOGRAPHIC FEATURES.

Historical.—The presence of at least two terraces in the Iowa river arm of the lake basin had been noted as early as 1891 by McGee.[174] However, from the map showing the surficial formations of northeastern Iowa accompanying McGee's classic monograph on the Peistocene History of Northeastern Iowa, it is apparent that the high terrace of this report was not recognized, although on page 432 McGee states: "The principal part of Iowa City, including the university campus, is on an elevated terrace of loess 60 feet above the river, and there is a narrow terrace just beyond the reach of the floods." The first part of McGee's description applies well to the high terrace of this report, for it lies about sixty feet above the river and also underlies most of Iowa City. Yet McGee's surficial map does not show it. His second terrace might correspond to the lower one as mapped and described in this report were it not for the following statement quoted from the same paragraph "and as the bottom lands expand below Iowa City they divide into terraces similar to and eventually merging with those of the Lower Cedar." It seems that McGee used the term "terrace" rather freely, for but two terraces, the high and the low, occur along Iowa river and these two eventually do unite with those of the lower Cedar. It appears also from the report on the "Geology of Johnson County"[175] that Calvin did not recognize two systems of terraces. No description of

172 Iowa Geol. Survey, Vol. XXVI, Report for 1915, 1917.
173 Idem, p. 136.
174 McGee, W J, The Pleistocene History of Northeastern Iowa, U. S. Geol. Survey, Eleventh Ann. Rep't., p. 432, 1891.
175 Iowa Geol. Survey, Vol. VII, 1897.

the upper one is found in his report and by comparing his surficial map with one showing the two sets of terraces as mapped by the writer, it is evident that at the time his report was written, in 1897, but one terrace was recognized. Hence, the mapping and describing of this important feature, the high terrace, appears for the first time.

Area.—By far the greatest development of the high terrace is confined to the east side of Iowa river, where it can be traced without interruption from Iowa City south to sections 10 and 15, Oakland township, Louisa county, a distance of nineteen miles. Throughout the middle portion of its extent, in Pleasant Valley township, Johnson county, the terrace maintains an average width of two miles. South of River Junction and Lone Tree the plain is wider so that a maximum width of almost six miles is attained three miles south of the above-mentioned villages. Still farther to the south, due to the encroaching of Iowa river, the terrace is restricted to a narrow neck less than half a mile wide connecting a somewhat wider portion in sections 3 and 10 of Oakland township, Louisa county. In sections 11 and 12, Pleasant Valley township, Johnson county, a narrow peninsular-like projection of the terrace extends westward for almost two miles. To the north of this hook, the high plain is marked by three indentations, the first of which is in section 7 and is made by the flood plain of a small tributary of Iowa river. The second indentation, which is in the form of a narrow valley and is occupied by the lower terrace, lies immediately to the north in sections 36 and 31 of East Lucas and Scott townships respectively. The third and largest irregularity consists of a well defined finger-shaped indentation, one and one-half miles long and half a mile wide. In the vicinity of Iowa City the terrace has a width of three miles.

On the west side of the river, the high terrace is not continuous, but occurs as small isolated remnants, the largest one of which is the valley of Old Mans creek, and occupies portions of sections 4, 5, 9, 15 and 16 of Liberty township and sections 31 and 32 of West Lucas township. Its width is between one-fourth and one-half mile and its length is four and one-half miles. This terrace is best developed in section 9 of Liberty township. Smaller remnants are found: (1) at the iron bridge crossing Iowa river to the city park at Iowa City; (2) on both sides of English river at the junction of the Iowa and English river valleys; and (3) in sections 16 and 17 of Union township, Louisa county.

The higher terrace rises distinctly above the lower one to the west, forming a very sharp and straight escarpment, which on the average is thirty feet high. Near Iowa City it lies sixty feet above Iowa river, while it is fifty feet high in the vicinity of Hills and thirty-two feet high in section 16, Oakland township, Louisa county. It has an elevation of 680 feet above sea level in the vicinity of Iowa City, but to the south it is lower, reaching a height of 670 feet near Hills, six to seven miles below Iowa City, and 660 feet two miles south of River Junction. In the lower two tiers of sections in Fremont township, Johnson county, the plain is again somewhat higher, approximating an elevation of 680 feet above sea level. From the elevations mentioned, is it apparent that the surface of the terrace has a much gentler slope—one and four-tenths feet per mile—than the intermediate terrace in Muscatine county. Immediately south of the island-like upland at Iowa City, but especially in sections 22, 23 and 26 of East Lucas township, the terrace border is bounded by low linear ridges of sand dunes. Dunes ten to fifteen feet high heighten the terrace escarpment of the peninsula-like extension of the main terrace in sections 1, 2, 11 and 12, Pleasant Valley township. Sand dunes are of common occurrence along the terrace margin south of River Junction.

Topography.—The most remarkable feature of the high terrace is its exceedingly straight border or escarpment where it is in contact with the low terrace. Where the flood plain of Iowa river abuts against it, as south of River Junction, the border is marked by numerous large irregularities of a type which is common to regions bordering courses of meandering streams. This straightness of the terrace margin where it is in contact with the lower terrace is not confined to the east side of the river, but occurs also on the west side and in the valley of Wapsinonoc creek north of West Liberty.

Topographically, the high terrace can be divided into northern and southern sections, the former including the area lying between Iowa City and the general latitude of Hills, the latter comprising all of the plain south of the above section. The northern section is characterized by a flat featureless surface in which the streams have cut but shallow and insignificant valleys. In sections 25 and 30, East Lucas township, the plain is especially flat as can be seen from the following photograph.

FIG. 16.—View showing the flat surface of the high terrace in section 25, East Lucas township, Johnson county.

The topography of the southern section is gently undulating. Compare figure 16 and figure 17. Its surface is marked by low elevations which in sections 13, 18, 19, 24, 25 and 36 of Pleasant Valley township rise twelve to fifteen feet above the general surface. Wherever the elevations are cut by roads they reveal a fine-grained sand without pebbles and undoubtedly they are dunes. Numerous undrained depressions, many of which are marshy and some of which contain ponds, were seen dotting the surface among the dunes. In sections 19, 24, 25 and 30 of Pleasant Valley township the surface of the terrace rises somewhat higher than the surrounding country. This led the writer to map it at first as a northwestward projection of Kansan upland. Closer examination, however, revealed the fact that the surface really consists of a series of broad and low elevations between which are undrained depressions. The material, as seen in the road and in the farm-yard in the northeast corner of section 30, consists of a fine-grained white to yellow structureless sand. Further work finally demonstrated a gentle break in the slope of the topography to the east of the supposedly tongue-shaped extension of the upland. Farther south, as in the lower tier of sections in Pleas-

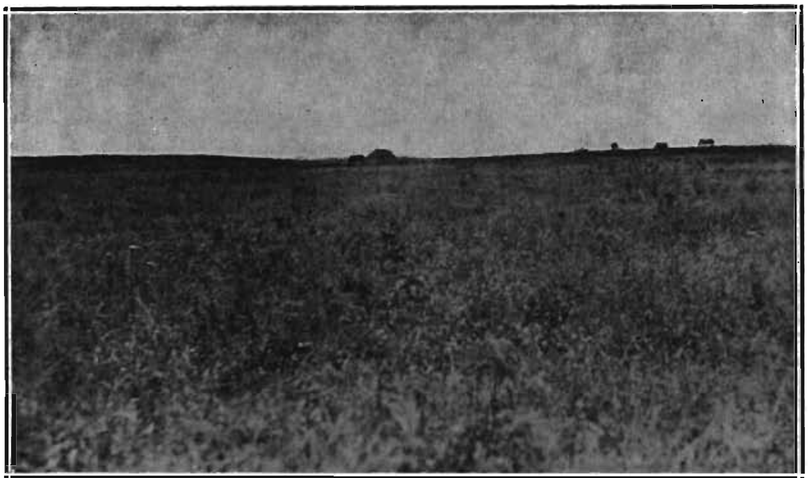


FIG. 17.—View showing the gently undulating topography of the high terrace, section 19, Pleasant Valley township, Johnson county. Compare with figure 16.

ant Valley township, the undulations are more pronounced, the dunes having a height of thirty to forty feet. Ponds are present between the undulations. Most of the dunes are not migrating but are under cultivation and at places are covered by groves of trees whose diameters measure as much as one and one-half feet. In general the undulations trend east and west.

Similar topography prevails south of the Chicago, Rock Island and Pacific railway tracks between River Junction and Lone Tree. The impression gained on viewing the topography is that the plain is the Kansan upland sloping gently west and southwest and the barometric elevations show this to be the case. The gentle upland slope was modified by some agency, which gave it the undrained-depression type of topography. This same impression is gained where the high and intermediate terraces come together in Muscatine and Louisa counties. In the center of section 33, Fremont township, Johnson county, there is a knoll somewhat higher than the surrounding land (Fig. 18), and the road which crosses it is very sandy toward the top of the ridge. To the south, the region lies forty to fifty feet lower, but rises again, however, to the same height at the edge of the terrace one mile distant. This knoll appears to

FIG. 18.—View showing the knoll on the high terrace in the center of section 33, Fremont township, Johnson county.

be the terminus of a high strip of country extending in a northwest direction through section 33 and the lower half of 29, into section 30.

Relation of the high terrace to other topographic features.—The high terrace is distinctly differentiated from the intermediate plain by a well defined escarpment which in section 3, Oakland township, Louisa county, reaches a height of forty feet. From the center of the western section line of section 11, Oakland township, to River Junction, the terrace is bordered by the present flood plain of Iowa river, with the exception of one locality. In sections 32 and 33, Fremont township, Johnson county, and sections 4 and 5 of Oakland township in

Louisa county, a small remnant of the low terrace joins the higher plain with a smoothly curving escarpment twenty feet high. It is in this part of the terrace lying south of River Junction that the sinuous border of the escarpment is found. The height of the high terrace above the flood plain differs from place to place. In the southern extension of the plain, in sections 9, 10, 15 and 16, Oakland township, where much of its prominence is lost, its surface lies between twenty-five and thirty feet above the flood plain. In section 4 of the same township, the escarpment bluff has attained a height of sixty feet. Twenty-five feet is the average height as far north as section 12, Fremont township, Johnson county, where the terrace bluff is forty feet high. North of River Junction, the high terrace is separated from the lower plain by the strikingly straight escarpment previously described. On the average, there is a vertical difference of thirty-five feet between the two surfaces.

On the west side of Iowa river, the larger terrace remnant in the valley of Old Mans creek is separated from the river flood plain by a steep bluff forty-eight feet high which gives it a height of thirty feet above the low terrace. Here, too, the characteristic straight escarpment is in evidence. The northern isolated remnant in the English river valley lies at least fifteen feet above the lower plain to the east and thirty-five feet above the bottom land of the river. The surface of the remnant on the south bank of the river is twenty-five feet above the low terrace.

MATERIALS AND STRUCTURE OF THE TERRACE.

Materials and structure.—An examination of all the exposures in the high terrace reveals the fact that most of the material is fine-grained, brown to white, horizontally bedded sand overlain by a deposit of loesslike clay which averages four feet in thickness. Sections in the northern part of the plain are extremely few in number. In the southwest quarter of section 24, East Lucas township, a few feet of horizontally bedded silt is exposed. Along Snyder creek, ten to fifteen feet of fine, horizontally stratified sand appears in the north bank of the creek at the crossing of the roads between sections 36 of East Lucas and 31 of Scott townships. The best outcrop of sands and silts is in the north bank of the wagon road cut between sections 13 and 24, Pleasant Valley township, two and one-half miles east of Hills and one mile east of a type section in the lower terrace to be described in the forthcoming pages. (See fig. 19.) The section follows:

FIG. 19.—View of an outcrop of fine sands and silts in the high terrace exposed in the north bank of the wagon road cut between sections 13 and 24, Pleasant Valley township, Johnson county.

TERRACE MATERIAL, HIGH TERRACE, TWO AND ONE-HALF MILES EAST OF HILLS.

		FEET
A.	Loesslike clay	2-3
B.	Extremely fine-grained, yellow to brown sand or silt. Stratification essentially horizontal, somewhat wavy. Lamination fine, lithological constituents uniform; exposed	3-7

Four cuts in the terrace surface in sections 31, 32 and 36 of the same township reveal the same type of fine horizontally bedded sands or silts. In these exposures, the stratification is horizontal and lacks the minor wavy undulations seen in the exposures east of Hills. It appears from the outcrop in the south bank of the creek in the northeast quarter of section 31 that the terrace is composed entirely of this fine-grained laminated material. Here the twenty feet of sand is exposed within two to three feet of the level of the rolling plain. Similar outcrops of fine silts are found in the center of section 4, Oakland township, Louisa county, four and one-half miles south of Lone Tree and in the south bank of the wagon road cut in the center of section 3 of the same township.

Only two exposures of the terrace material were seen in the terrace remnant in the valley of Old Mans creek. One of these is in a small gully in the terrace escarpment in the western part of section 10, Liberty township, five miles south of Iowa City. The materials are as follows:

TERRACE MATERIAL, SECTION 10, LIBERTY TOWNSHIP, JOHNSON COUNTY.

		FEET	INCHES
A.	Brown to reddish fairly coarse-grained sand, grading into a whitish to grayish clay or silt, leached and structureless	17	
B.	Reddish to brownish black gumbo-like material, sticky when wet, practically free from grit. Material thoroughly leached. Surface uneven		½-13
C.	Buff to ash-colored clay, gritty, pebbleless, leached; exposed	2	

The relation of the gumbo-like material, B, to the other material is indicated in the diagram below, figure 20. The top

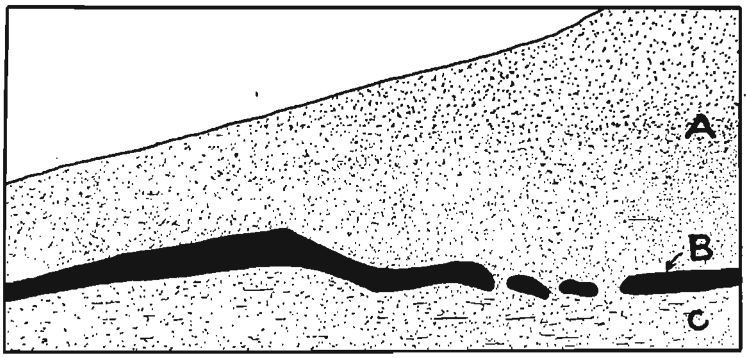


FIG. 20.—Diagram showing the relation of the gumbo-like material, B, to the material A and C.

of the terrace at this locality is thirty-two feet above the flat to the east, and the black sticky material, B, is fifteen feet above the flat. A similar gumbo-like clay outcrops one hundred yards to the southeast at practically the same level. Also the log of the well at the house two hundred feet or so north of the first outcrop indicates a black band having a thickness of six inches. This well is approximately sixty feet deep and the black layer is struck forty-five feet below the surface. The owner of the well also reported sixteen feet of gravel below the sticky material. The top of the terrace at the house is forty-eight feet above the lowland to the east, thus bringing the black layer about three feet above the lower flat or twelve feet lower than the deposit at the first described locality. Another exposure is half a mile farther to the southwest in a shallow ditch on the east side of the wagon road at the corner of sections 9, 10, 15 and 16. Four or five feet of leached sand and clay similar to those seen at the first locality is exposed here also. The layers, which are thinly laminated, show more or less irregular bedding, which, however, can be explained readily as being due to the settling of the material after the road was constructed. A deposit of four to five feet of loesslike clay lies over the sands. The surface of the terrace at these sections is flat.

Most of the outcrops seen south of the railroad tracks between River Junction and Lone Tree differ somewhat from those to the north. In addition to the fine-grained sands or silts of the northern exposures, the southern sections show layers of coarse-grained sand and fine pebbles. Cross-bedding also is more in evidence in the coarser material and it is noted that the cross-bedding is fine and variable in direction. It is further worthy of remark that the material is of low textural range, large pebbles being entirely absent. These cross-bedded layers are interstratified with the predominatingly finer horizontally bedded material. A typical section follows:

TERRACE MATERIAL, HIGH TERRACE, SOUTHWEST CORNER, SECTION 24, FREMONT TOWNSHIP, JOHNSON COUNTY.

		Feet
A.	Loesslike clay	4
B.	Medium to coarse-grained yellow to brown sand, very fine cross-bedding	1
C.	Very fine dense bluish sand with irregular lenses grading into a coarse-grained sand which is highly and finely cross-bedded; numerous small pebbles and pebble pockets	8
D.	Brown, horizontally stratified sand containing thin layers of very small pebbles, lower portion coarser grained and cross-bedded	12
E.	Dark brownish to blue-black joint clay containing much wood. Surface of till covered by bowlders of all descriptions of which many are in the form of shingle; exposed to water's edge	10

The cross-bedding of sand C, which is rather unusual for the high terrace deposits, is represented by the diagram, figure 21. It may be noted that a good many of the gravelstones, cobbles and bowlders which were seen lying between the stratified materials and the till in the various exposures along the bank of the Iowa river are flat or slablike. Not only is this true of the softer local limestone, but also of the harder igneous material. (See Fig. 22.)

FIG. 21.—Detail of cross-bedding of bed C in the high terrace sands exposed in the southwest corner of section 24, Fremont township, Johnson county.

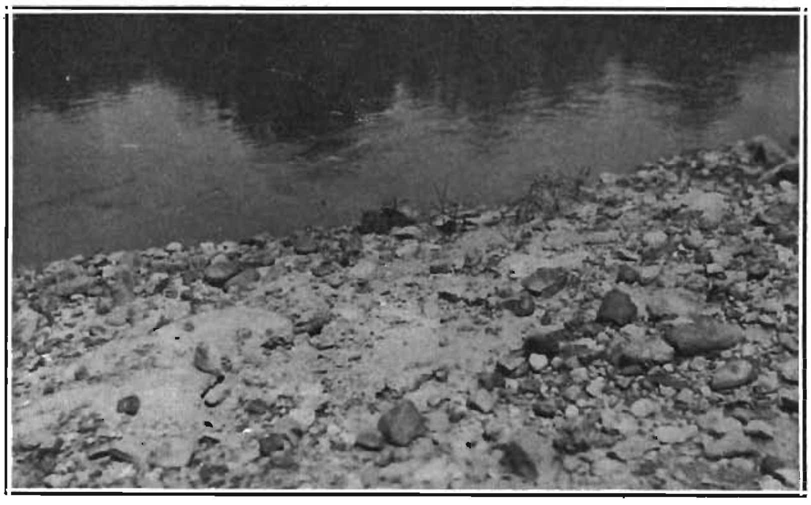


FIG. 22.—View of the slablike igneous bowlders lying on the surface of the till and beneath stratified terrace deposits in section 23, Iowa township, Washington county.

THE WILTON VALLEY TERRACE.

Area and topography.—According to Udden, the terrace along the course of Mud creek up to Durant is a northeastern extension[176] of his West Liberty Plain, or the intermediate terrace of this paper. Because of the difference in the material of the two terraces and because of the interrupted profile of the gradient of their surfaces when these are connected, as illustrated in figure 23, the writer is of the opinion that the Wilton valley terrace is not an extension of the intermediate plain but rather a higher terrace corresponding to the high terrace in Johnson county. The terrace is continuous and can be traced eastward without a break on both sides of Mud creek, from sections 2 and 11, Moscow township, for a distance of over seven miles beyond Durant. The terrace is well defined and its surface is flat (see figure 24) and not obscured by sand

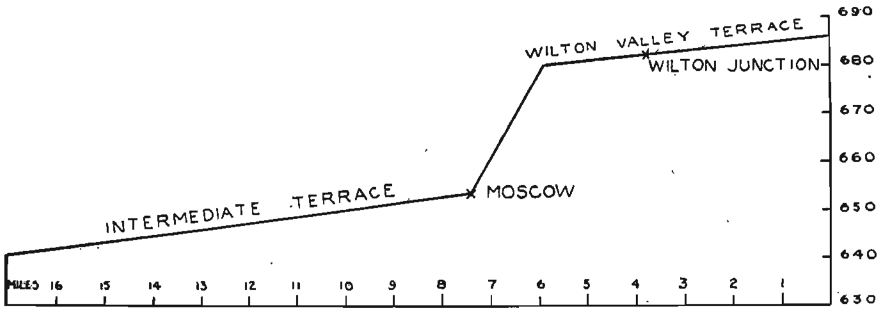


FIG. 23.—Diagram showing the interrupted profiles of the surfaces of the Wilton Valley and Intermediate terraces when the two are connected.

dunes. In width, the northern part averages half a mile, whereas south of the creek the terrace is three-fourths to one mile wide. Its surface, which lies thirty to forty-five feet above Mud creek, meets the valley walls in a gentle slope.

Materials and Structure.—Exposures in the terrace are fairly numerous. Good outcrops are to be had in almost every section through which Mud creek flows, from section 11, Moscow township, to the village of Durant. In general, the material composing the terrace is as follows:

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176 Iowa Geol. Survey, Vol. IX, p. 257, 1899.

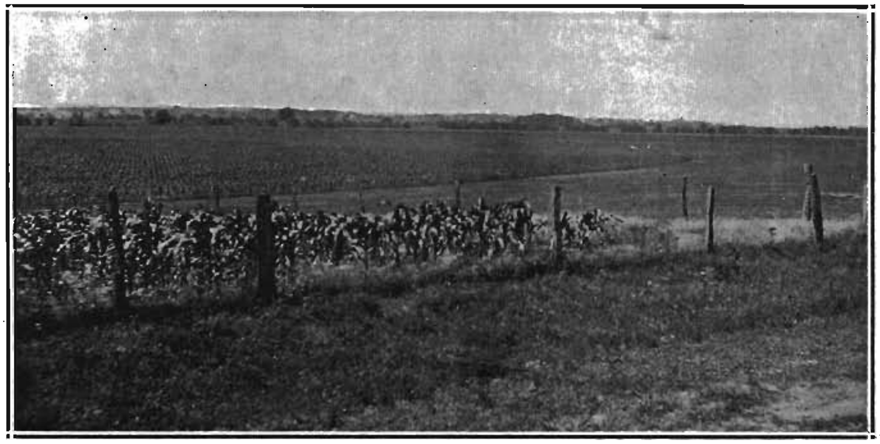

FIG. 24.—View of the Wilton Valley terrace showing its flat surface and the gentle slope of the valley walls. View taken one mile east of Wilton Junction.

A. Loesslike clay.

B. Stratified sand, usually fine-grained.

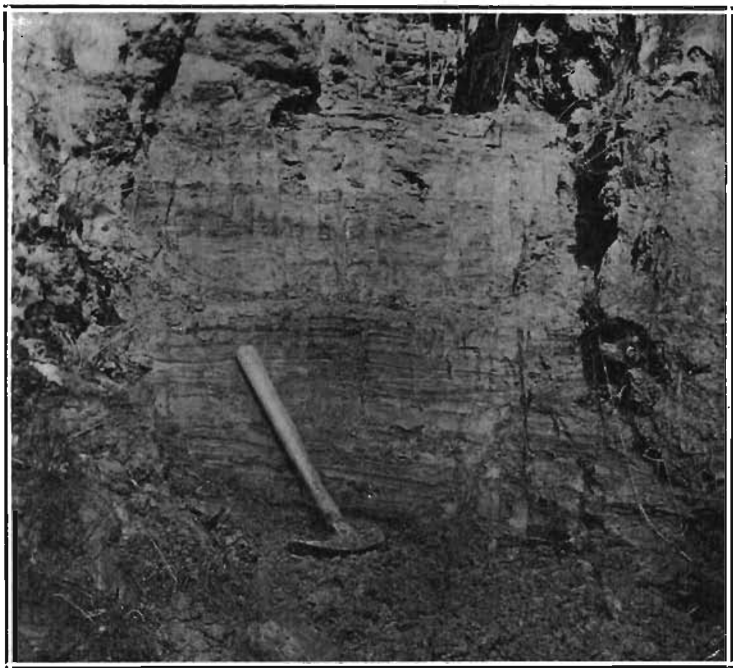

FIG. 25.—View showing the finely laminated silts exposed in the Wilton Valley terrace, in the southwest quarter, northwest quarter of section 8, Wilton township, Muscatine county.

C. Finely laminated silts or clays.

D. Stratified sand, more gravelly to the west.

The deposits seen in the various outcrops are of such a uniform character that they may be represented by the two following typical sections, one showing the prevalence of finely laminated silts or clays in the eastern half of the valley and the other showing a predominance of fine stratified sands in the western end of the valley. The type exposure of the laminated silts or clays is in the southwest quarter of the northwest quarter of section 3, Wilton township, three miles east of Wilton Junction. At this place Mud creek makes a sharp

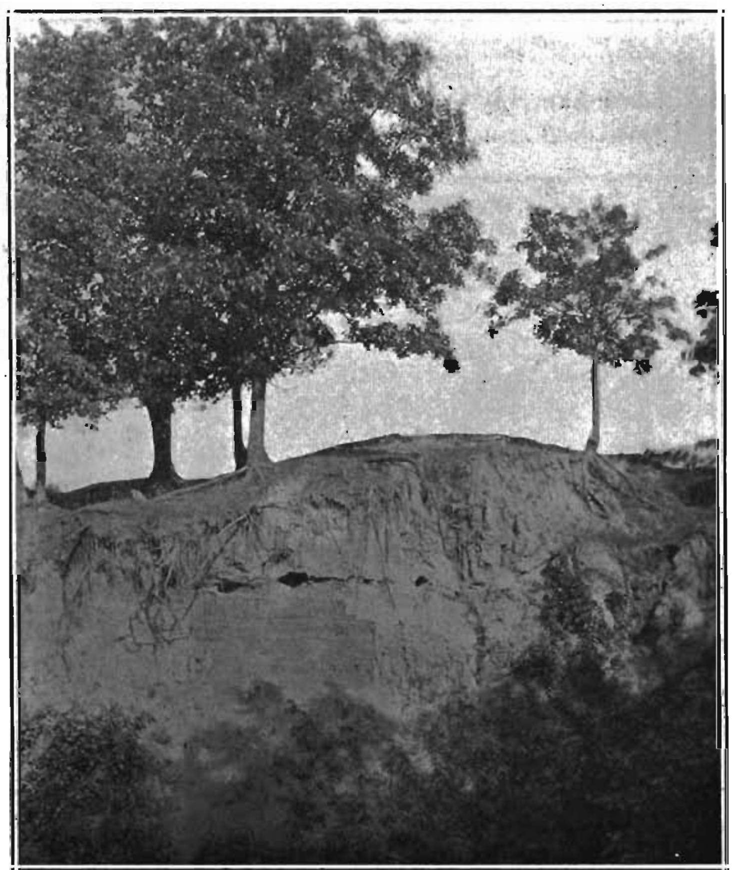

FIG. 26.—View showing the laminated silts of figure 25 exposed within a few feet of the terrace surface.

bend toward the north. The exposure is in the south and east bank of the terrace escarpment which rises thirty-five feet above the creek level. Figures 25 and 26 illustrate the materials at this place. The section is as follows:

TERRACE MATERIAL, WILTON VALLEY TERRACE.
Sw. ¼, Nw. ¼, SEC. 3, WILTON TOWNSHIP,
MUSCATINE COUNTY.

		Feet
A.	Loesslike clay	1-5
B.	Fine-grained thinly bedded yellow sand above the finely laminated silts or clays, laminæ about twenty to an inch	34

The sand, silts or clays are free from all pebbles. The stratification, which is extremely fine, is horizontal; however, minor undulations, as figure 26 shows, are in evidence.

The section typical of the terrace material in the west half of the valley is shown in the following photograph, figure 27. This outcrop is in the west bank of the wagon road cut between sections 11 and 12 of Moscow and Wilton townships respectively, one mile south and west of Wilton Junction. The terrace at this place is forty-six feet high and the outcrop is twenty feet above the creek.

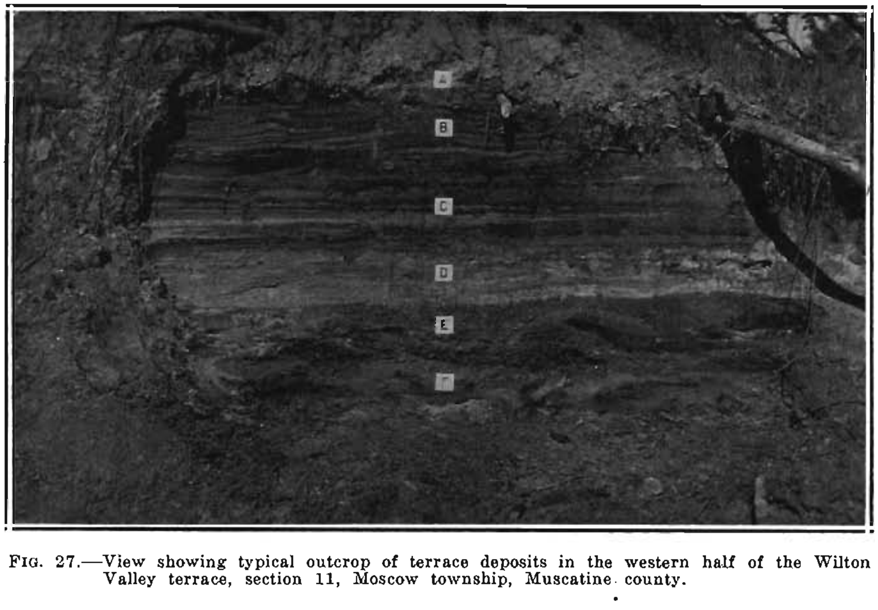

FIG. 27.—View showing typical outcrop of terrace deposits in the western half of the Wilton Valley terrace, section 11, Moscow township, Muscatine county.

TERRACE MATERIAL, WILTON TERRACE,
WEST HALF SEC. 11,
MOSCOW TOWNSHIP, MUSCATINE COUNTY.

		Feet	Inches
A.	Brown loess	2-3	
	Sandy and silty deposit with small gravel or pebble pockets	2-3	
B.	Finely laminated brownish sand to silt, no pebbles, bedding practically horizontal	1	
C.	White to brown sand, white sand fine-grained, few scattered pebbles; brown and lower sand coarser and containing numerous small pebble pockets	8	
D.	White fine-grained sand, occasional pebbles		
E.	Coarse brown sand, numerous pebbles		6
F.	Ash-colored silt, very fine, no pebbles, laminated; exposed		6

TERRACE REMNANT IN CEDAR COUNTY.

A remnant of what appears to be a high terrace is present in sections 13, 14, 23 and 24 of Iowa township, Cedar county, on the west bank of Cedar river. The top of this terrace remnant is flat and lies thirty-five feet above another terrace to the east which in turn is twenty feet above the water level of Cedar river. No exposure was seen in it and the only clew as to the nature of its material and structure is obtained from its sandy surface and an exposure of bedrock in the creek bed in section 14 where the high terrace meets the bluffs of the upland. This suggests a rock terrace partly covered over with loose sandy deposits. The terrace is only half a mile wide.

TERRACE NORTH AND NORTHWEST OF WEST LIBERTY.

The high terrace north and northwest of West Liberty along the course of West Branch or Big Slough creek and Wapsinonoc creek was mapped on the basis of topographic position. The town of West Liberty is built on this terrace, which rises about thirty feet above the intermediate plain. The terrace can be very readily traced up to the above-mentioned creeks but they have not incised their valleys sufficiently to reveal the nature and structure of the materials. The noteworthy feature of this terrace is its regular and straight border, a feature characteristic of the high terrace wherever it is in contact with the lower terrace. This terrace is Udden's other extension[177] of the West Liberty Plain.

177 Iowa Geol. Survey, Vol. IX, p. 257, 1899.

RELATIONSHIP OF HIGH TERRACES.

In the neighborhood of Hills, Johnson county, the high terrace has an elevation of 670 feet above sea level which agrees well with that of the western remnant in the valley of Old Mans creek. This height corresponds with that of the high terrace at West Liberty where the terrace, as recorded by the Chicago, Rock Island and Pacific Railway depot elevation, is 673 feet. The lower end of the Wilton Valley terrace, also in the same straight line, has an elevation of 670 feet. In sections 29 and 30 of Scott township, Johnson county, the elevation of the terrace is 680 feet above sea level. Five miles directly east, the northwest extremity of the high terrace north and northwest of West Liberty lies at 681 feet. Furthermore, the small remnant of the high terrace on the west bank of Iowa river at Iowa City, near the city park, is at 680 feet. Lastly, the two isolated remnants of the high terrace on both sides of English river lie at approximately 640 feet, which is also the approximate elevation of the terrace east of Iowa river at River Junction. Thus, it seems that in so far as elevations are concerned, there is some relationship between the high terrace and its remnants in Johnson county and the two high terrace remnants in Muscatine county.

THE LOW TERRACE.

Area.—The low terrace is confined to the western or Iowa river arm of the lake basin. Unlike the other two terraces, this terrace is not continuous, but is represented by remnants large and small. Its surface lies, in general, twenty feet above Iowa river or somewhat less above the bottom-lands and twenty to forty feet below the high terrace. Where it is in contact with the high terrace, as in Pleasant Valley township, Johnson county, the line of separation is regular, whereas its escarpment along the river or flood plain is more or less sinuous. Remnants of the terrace occur on both sides of Iowa river. Along the stream courses of Old Mans creek and English river south of Iowa city, the terrace is represented by "mere remnants at the bends of"[178] Iowa river. These 'mere remnants'

[178] Alden, Wm. C., and Leighton, Morris M., The Iowan Drift: Iowa Geol. Survey, Vol. XXVI, p. 136, 1917.

have been described by Leighton[179] and are at the following places.

1. West side of the valley of Pardieu creek about one mile below the North Liberty Plain in the west central part of section 29, township 80 north, range 6 west.
2. Along the north side of the ravine running parallel with the Cedar Rapids and Iowa City Interurban from Swisher to Cou Falls.
3. On the north side of the bend of Iowa river just north of Iowa City and on the west side of the tributary that dissects the valley wall.
4. Just above Mehaffey bridge, in the southeast quarter of section 32, township 81 north, range 6 west.

The remnants are all small, having an average length and width of one-fourth and one-eighth of a mile respectively and a height above the river of about thirty feet.

South of Iowa City the terraces are better developed and of greater dimensions. Half a mile south of the Iowa City limits in West Lucas township, the terrace is one and one-fourth miles wide and on the east side of the river in East Lucas township, sections 34, 35 and 36, it is approximately two miles wide. However, the average width of the low terrace in the Iowa river valley is about three-fourths of a mile. The largest parts of this terrace are that in the valley of Old Mans creek, where it is ten miles long and half a mile wide and that along the course of English river, where it is seventeen miles long and about a mile wide. Two insignificant remnants, one on each side of the river, are present at the intersection of Johnson, Louisa and Washington counties. It is possible that the low terrace is represented along Cedar river north of Cedar Valley, in Gower township, Cedar county.

Topography.—The surface of the low terrace is flat except where it is interrupted by a few shallow gullies of young streams.

Materials and Structure.—Exposures of materials are limited to the river banks. In contrast with the deposits seen in the high and intermediate terraces, the materials of the low terrace are coarser, contain more gravel layers, have a higher

179 Iowa Geol. Survey, Vol. XXV, pp. 134-138, 140, 141, 1914.

textural range and consist predominantly of sands with extremely little silt or clay. In structure there is also a difference. Whereas the high and intermediate terraces contain thinly and horizontally bedded deposits with minor cross-bedding, the prevailing type of structure of the low terrace is well developed cross-bedding and pocket-and-lens stratification. Of all the exposures observed, those at the following three places may be cited as the best and most typical:

1. Johnson county, Pleasant Valley township, center of the northeast quarter of section 33. The outcrop is in the east bank of a slough of Iowa river, one and one-half miles east of Hills and one mile southeast of a typical high terrace exposure. The terrace is twenty-one feet above water level and approximately 640 feet above sea level.
2. Johnson county, Liberty township, central part of the northeast quarter of section 27, one and one-fourth miles south of Hills. The materials are in the west bank of Iowa river.
3. Washington county, Iowa township, northeast corner of northeast quarter of section 33. The outcrop is in the southwest bank of Iowa river.

A composite description of the three outcrops follows. The upper three to six feet consists of loess or a brownish loesslike clay which overtops a fine to medium-grained highly cross-bedded sand which has a predominant dip to the south. This bed is two to four feet thick and numerous small granite, chert and limestone pebbles one inch in diameter are scattered through it. Pockets of laminated clay are visible locally. Beneath this layer of sand is a white sand which contains near its top small pockets of quartz, chert, greenstone and other pebbles. The sand also is cross-bedded and peppered with little pebbles. Its thickness is three feet. Beneath the white sand is a coarse, brown sand containing numerous pebbles which measure one inch in all three dimensions. Most of the sand is cross-bedded with a dip toward the south. Dip measurements read from twenty to thirty degrees. At places, as at the Washington county exposure, there is a change in the direction of dip of the cross-beds. Numerous fine gravelly layers are distributed throughout this sand in the form of pockets which pinch out laterally. Some horizontal as well as irregular or wavy bedded layers occur throughout the deposit. Beneath the stratified material, which is exposed within one to ten feet of the water's edge, is a dense bluish to black till whose surface is covered by many pebbles, cobbles and bowlders, a large proportion of which are slablike. (See fig. 22, page 155.) Laminated clays in the low terrace are exposed in the south bank of Ralston creek in the center of section 15, East Lucas township, south of Iowa City.

Another outcrop which calls for especial attention is the one in the southwest quarter of section 34, West Lucas township, about four miles south of Iowa City. The material is all stratified, is coarse and consists of sands and gravels. The deposit is exposed in a former gravel and sand pit of the Iowa City-Kalona branch of the Chicago, Rock Island and Pacific Railway. The terrace rises fifteen feet above the flood plain of Iowa river and is about one-eighth of a mile wide. A diagram and section follow:

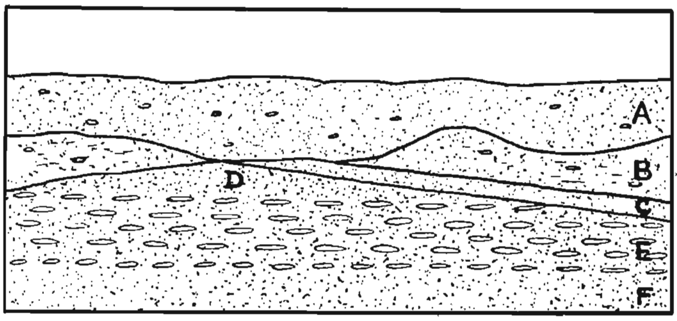

FIG. 28.—Diagram of the terrace materials seen in the low terrace in the Sw. ¼ of section 34, West Lucas township, Johnson county.

TERRACE MATERIAL, LOW TERRACE, SOUTHWEST QUARTER, SECTION 34, WEST LUCAS TOWNSHIP, JOHNSON COUNTY.

		INCHES
A.	Dark sand peppered with pebbles or small gravel, some well rounded. Occasionally large pebbles are found. Lower surface somewhat irregular	6-15
B.	Coarse sand lighter than above, stratified, containing few large pebbles; on the whole, pebbles smaller than in A	0-6
C.	Thin layers of coarse stratified sand, the upper half of which is blackish and contains a few pebbles; lower half of a brownish color	2-3
D.	A sand similar to B	0-5
E.	Coarse stratified gravel and sand. Gravel consists of igneous material and limestone in equal parts; textural range high, from small sand grains to bowlders nine by six by four inches. Many of the gravels are in the form of slabs or shingle. Some of the limestone slabs are	

	one-eighth to one-fourth of an inch thick, six to seven inches long and four inches wide. This slablike form is not confined to the limestone, but is common also to the harder igneous material	12-24
F.	Coarse stratified sand; exposed	1-2

The log of the well at the house immediately west of the outcrop shows that there is about two feet of soil followed by three feet of coarse stratified sand below which the gravel is encountered. The owner of the well also reported that where the water level in the terrace is reached, the sand is coarse but of uniform texture. According to this same farmer, the gravel lies at different distances below the terrace surface, generally not very far beneath it, however.

THE FLOOD PLAINS OF THE LAKE BASIN.

The flood plain of Cedar River.—The flood plains of the two master streams have different widths and are at different depths below the levels of the adjacent terraces into which the modern valleys have been cut. Their margins, however, are practically everywhere characterized by sinuous river-scarred escarpments. The bottom lands of Cedar river maintain a fairly uniform width of two and one-fourth miles to a point about three miles north of Cone where the valley is constricted to one and one-half miles. This width is maintained within two miles north of the Muscatine county line from which point to the junction of Iowa and Cedar rivers, the flood plain is no wider than half a mile. In the northern part of Muscatine county, in Goshen township, the bottom lands lie thirty-seven to forty-three feet below the intermediate plain. As the flood plain is traced southward, the difference between its surface and that of the intermediate terrace becomes less and less until in Orono township it is twenty-seven feet and in Louisa county but twenty feet. The flood plain in turn lies on the average five feet above the river. Its surface is characteristically flat, sandy and marshy and scarred by numerous abandoned river channels, old sloughs and ox-bow lakes. On the whole, the drainage is defective and most of the land is barely fit for agriculture.

The flood plain of Iowa river and its tributaries.—The flood plain of Iowa river and its tributaries is in all respects similar to that of Cedar river. The bottom lands of Iowa river are on the average twenty feet below the surface of the low terrace and thirty-two to forty-eight feet lower than the high terrace in the valley of Old Mans creek and forty to forty-five feet lower than the high terrace near River Junction. At other places, in sections 24, 25, 31 and 32, Fremont township, Johnson county, differences in elevation between the flood plain and the high terrace ranging between twenty-two and thirty feet are more common. A maximum vertical difference in height of sixty feet between the high terrace and the flood plain is reached in the center of section 4, Oakland township, Louisa county. The most conspicuous features of the Iowa bottom lands are the two large extensions of the flood plain into the high and intermediate terraces in Oakland township. The most easterly one, occupying parts of sections 11, 12, 13, 14, 15, 22 and 23, is especially noteworthy. On the west side it is bordered by the high terrace and on the north and east by the intermediate terrace, whose surface lies on the average thirty feet higher than the flood plain. Its outline or border is remarkably regular with no notable indentations. Its width is uniform and is a little more than one mile. The lowland, which is marshy and a favorite ground for duck hunters, is traversed by Prairie creek. Two crescentic ponds or lakes dot its surface, one in the northwest corner of section 13 and adjoining parts of sections 12 and 14, the other in the southeast corner of section 15, the southwest corner of section 14 and the northern part of section 23.

The average width of the Iowa river flood plain between River Junction and a point almost four miles north is two and one-half miles. Thence the bottom lands are narrower, having at first a width of one and one-half miles, then one mile and finally at Iowa City scarcely one-eighth of a mile. South of River Junction, the flood plain is two and one-half miles across, but is abruptly constricted to half a mile in sections 25 and 26 of Iowa township, Washington county. The flood plain widens again south of these two sections until finally a maximum width of three miles is attained in the first large indentation in Oakland township, Louisa county. Between the two large extensions of the Iowa river lowland, the flood plain is confined to a width of only one-fourth of a mile or less. South of Gladwin as far as the junction of the Iowa with the Cedar, the bottom lands range from one-third to one mile in width. The flood plains of the tributaries of Iowa river are insignificant and need no further comment.

CHAPTER VI.

EVIDENCE AND ORIGIN OF EXTINCT LAKE CALVIN.

Evidences of Extinct Glacial Lakes.

In a consideration of extinct glacial lakes, the most common evidences cited for their previous existence are generally those enumerated by Upham and listed as follows:

1. "Their channels of outlet over the present watersheds.
2. Cliffs eroded along some portions of the shores by waves.
3. Beach ridges of gravel and sand, often on the larger glacial lakes extending continuously through long distances.
4. Delta deposits, mostly gravel and sand, formed by inflowing streams.
5. Fine sediments spread widely over the lacustrine area."[180]

To these may be added several others as for instance, ice-rafted bowlders, bowlder walls, rounded shore lines between places of indentation and associated deposits along the shore lines.

Discussion and Interpretation of Features of the Lake Calvin Region.

Although the existence of Lake Calvin has been accepted by most geologists familiar with the Lake Calvin basin, absolute proof of the former lake's existence has never been presented. Udden's work was confined to Muscatine county and the evidences cited by him in his report on Lake Calvin[181] do not establish the certainty of the presence of the ancient lake, especially in the light of our present knowledge of the Pleistocene. Furthermore, doubt regarding Lake Calvin has been presented personally to the writer and has also been indicated elsewhere as may be seen from the following: "It is not known whether this gravel (a deposit in the intermediate terrace or Udden's West Liberty plain) is a sheet deposit formed along a delta front encroaching on a lake, or was deposited by a stream the width of the present plain or was laid down in long narrow

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180 Upham, W., Lake Agassiz: U. S. Geol. Survey Monograph XXV, p. 195, 1895.

181 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 350-357, 1899.

strips in the channel of an aggrading stream perhaps no larger than the Cedar of today.''[182] It has also been suggested that the sediments in the lake basin in Muscatine county were laid down ''by a stream which is supposed to have had its course through it (the intermediate terrace) with some lacustrine influence.''[183]

In view of the above opinions, it now becomes necessary to carefully and critically study all features found in the lake region which might throw some light on the question whether Lake Calvin did or did not exist. An unbiased analysis of such features ought then to show whether the Lake Calvin basin is to be attributed to:

1. lacustrine influence
2. alluvial influence
3. or a combination of 1 and 2.

With this view in mind, the following topics or features are presented for careful and critical study:

1. Theoretical considerations.
2. The Mud-Elkhorn creek valley.
3. The temporary Mississippi river channel of Leverett.
4. Laminated silts, clays and sands in the lake basin.
5. Terraces in the lake basin.
6. Rounded bluff lines in the lake basin.
7. Bowlders in the lake basin.
8. Certain gravel deposits in the lake basin.
9. The Illinoian upland within and without the lake basin.
10. A comparison of the width of the valley in and outside of the lake basin.

THEORETICAL CONSIDERATIONS.

Discussion.—Leverett[184] has conclusively demonstrated that southeastern Iowa was invaded from the east by the Illinoian ice sheet and that during this time Mississippi river must have been displaced. The blocking up of the valley by the ice sheet undoubtedly resulted in a ponding of the waters probably giving rise to a lake as the waters rose until finally an outlet or spillway was reached. As the mouth of Wapsipinicon river

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182 Norton, W. H., and Others, Underground Water Resources of Iowa: U. S. Geol. Survey Water Supply Paper 293, p. 465, 1912; Iowa Geol. Survey, Vol. XXI, p. 560, 1912.

183 U. S. Department of Agriculture, Soil Survey of Muscatine County, Iowa, p. 22, 1916.

184 Leverett, F., Illinois Glacial Lobe: U. S. Geol. Survey Monograph XXXVIII, 1899.

was blocked by the Illinoian ice sheet[185] (Fig. 29) the waters of the Mississippi were dammed back as far as Maquoketa river from whence they escaped westward as far as Preston in Jackson county. At Preston, the Maquoketa river valley is connected from the south by the wide and well developed Goose Lake channel which extends southward for over nineteen miles to the valley of Wapsipinicon river. Due to the closing of the

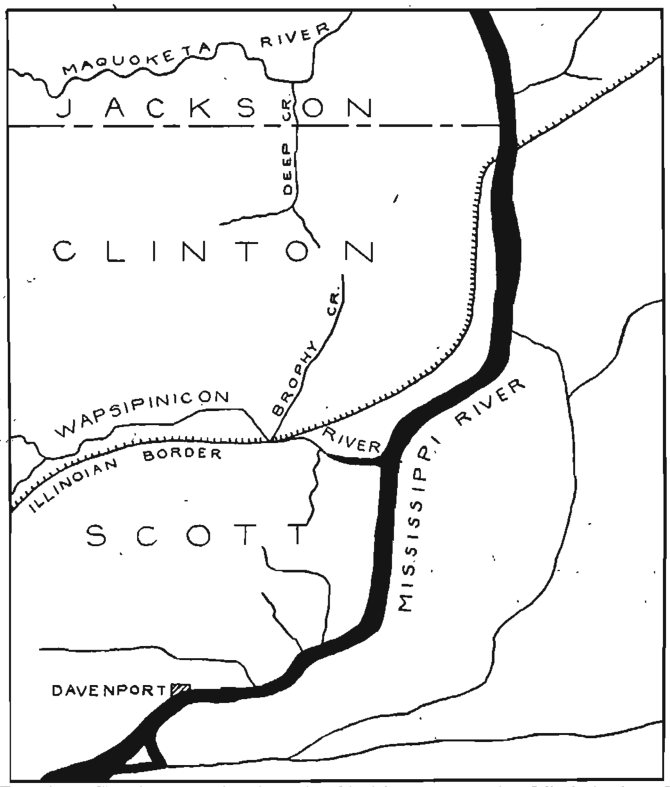

FIG. 29.—Sketch map showing the blocking up of the Mississippi and lower portion of the Wapsipinicon river valleys. (Modified after Carman)

mouth of that river by the ice barrier the combined waters of Mississippi, Maquoketa and Wapsipinicon rivers were forced westward to the mouth of Mud creek from whence the confined waters found their way southward over the low divide to Elkhorn creek and finally into Cedar river at Moscow. From here

185 Carman, J. Ernest, The Mississippi Valley Between Savanna and Davenport: Illinois Geol. Survey, Bull. 13, p. 62, and fig. 15, p. 38, 1909.

the four streams pursued a southerly course to Columbus Junction, Louisa county, where Iowa river added its waters to that of the others. Since the passage of these waters was still obstructed on the east by the ice wall of the Illinoian glacier and on the other sides by high Kansan bluffs they were still dammed back and must have risen until the level of the abandoned channel discovered and mapped by Leverett[186] was reached. As has been shown by Leverett[187] this ancient water-course can be traced southward, westward and eastward across several counties until it joins the present Mississippi river valley immediately below Fort Madison in Lee county. That the course of Mississippi river during the Illinoian stage of glaciation followed the course just outlined is not disputed. That the ponding of the combined waters of Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa rivers together with that of the melting ice sheet necessarily gave rise to a quiet body of water in the lake basin area or that aggradation kept pace with the increasing influx of water so that stream conditions existed all the time or that a combination of the two may have resulted is not so obvious.

Interpretation.—The fact remains that when the Illinoian ice sheet occupied the position shown by its deposits as indicated on Plate VIII, Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa rivers with their tributaries were blocked on one side by an ice wall and on the other by uninterrupted Kansan bluffs 120 to 140 feet high. That the waters of these combined streams were ponded is evident. The question arises: would this ponding of the stream give rise to a lake or is it possible that in some way or other fluvial conditions were maintained? It is true that the ponded waters were able to spread over a considerable area, which may have resulted in shallow water conditions. However, it is hardly conceivable that deposition was so rapid as to have kept pace with the rising of the water, especially since the combined waters of several large streams were involved, not forgetting the water coming from

186 Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, Vol. XI, p. 64, 1901.
187 Leverett, F., The Illinois Glacial Lobe: U. S. Geol. Survey Monograph XXXVIII, pp. 89-97, 1899.

the melting ice sheet. Furthermore, most of the aggradation must be attributed to the melting Illinoian ice itself and especially is this true towards the southern half of the lake basin where no large streams empty into the basin. Would this aggradation account for the relative thinness of the Illinoian deposit? It is a fact that the Illinoian drift is thin, but is it not more logical to explain this fact on the basis that the ice sheet had been greatly reduced in thickness, first because it was practically at its maximum distance from its source and secondly because in passing over from Illinois into Iowa, the ice had to fill up the wide valley of the Mississippi, thus permitting only its upper and less heavily laden portion to advance into Iowa? Such a diminution in thickness of the ice would necessarily mean a minimum amount of glacial erosion and hence a minimum amount of material for deposition. Hence, the terrace materials are not to be thought of as being the result of deposition of a stream the width of the terrace. That it does not take much to cause ponding of waters to form a lake is illustrated in the case of Lake Pepin, Wisconsin. Lake Pepin is an expansion of Mississippi river. It is from one mile to two and one-half miles wide and about twenty-two miles long, covering an area of approximately thirty-eight and one-half square miles. The lake is a result of the building up of a delta by Chippewa river. This river having a higher grade than that of the Mississippi is able to carry more and coarser material than the master stream is able to remove. If the incomplete obstruction of the Mississippi's course, as at the mouth of the Chippewa, is sufficient to cause the formation of a lake then it is certain that the complete blocking of the Iowa-Cedar river valley by the Illinoian ice sheet would give rise to Lake Calvin.

Thus it appears to the writer that ponding of the combined waters of Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa rivers must have resulted in the formation of a lake in which the sediments of the terraces were deposited.

THE MUD-ELKHORN CREEK VALLEY.

Discussion.—Of utmost importance in the consideration of the former existence of glacial lakes are the inlet and the outlet, especially the latter. If there really existed a lake with an inlet, some evidence of the latter might be manifested either in the form of the topography or in the nature of the sediments found in the inlet. The only possible inlet of Mississippi river to Lake Calvin was by way of Mud and Elkhorn creek valley as outlined under Theoretical Considerations. A careful study of this valley is therefore very important.

The valley occupied by Mud creek is well defined and ranges in width from one and one-half to a little over two miles. It unites with the large valley of Cedar river at Moscow and extends eastward for over seven miles past Durant. The valley walls, although more sharply defined at some places than at others, merge, in general, gradually into the conspicuous feature of the valley, the wide terrace described in chapter V as the Wilton Valley terrace. The surface of this terrace is flat and unobstructed by sand dunes and is continuous save for the course of Mud creek which has incised for itself a narrow flood plain thirty to forty-five feet below the terrace surface. At Durant an island-like ridge separates the valley into two branches, one trending in a northeasterly direction following what is known as Elkhorn creek and the other continuing eastward along Mud creek. Of the two branches, the northeast trending valley is the more conspicuous. For over two miles its course is direct and its width is scarcely over one-half of a mile. The valley walls are well developed and sharply outlined. The other branch continues eastward along Mud creek for about three miles and thence extends northward, meeting the Elkhorn valley in sections 19 and 20 of Cleona township in Scott county. All exposures of sediment in the valley are limited to the area between Moscow and Durant and consist chiefly of fine stratified sand and laminated silts or clays. Calvin in speaking of these sediments states "The fineness of the material, the regular stratification and absence of organic matter, indicated that at the time of the imbedding of the skeleton, the locality was covered with comparatively deep, clear and still water . . . . . The topography of the surrounding country and the nature of the drift itself, favored the idea that a lake at one time covered the territory of the West Liberty plain and reached up to Wilton, and that sediments from some inflowing river had aided in filling this lake.''[188]

The valley in which Elkhorn creek flows continues its course northeastward over the very gentle divide into the valley of Mud creek without either being constricted or losing its identity. The divide separating the headwaters of the north-flowing Mud and the south-flowing Elkhorn creeks lies at an elevation of about 720 to 725 feet above sea level and is so flat and poorly drained that several ponds and marshes cover its surface. The rise between the two creeks is so imperceptible that were it not for the fact that the creeks are seen to flow in opposite directions, a col would not be suspected. The divide is in sections 19 and 20 of Cleona township, Scott county, and is over one and one-half miles wide. The valley thence follows the course of Mud creek for over nine miles to Wapsipinicon river. Mud creek itself is an insignificant stream. Near its head, it is but a few feet across and from three to five feet deep, but it increases in size somewhat toward its mouth where it is four to five rods wide and six to seven feet below the valley floor. Because of its extreme youth there are no exposures along its course. Outcrops are lacking on the valley slopes also because of their gentleness. Another noticeable feature of Mud creek valley is that the wide valley floor extends up into the tributary valleys so that the latter near their mouths are exceptionally wide. ''It is believed that these broad flood plains (of the tributaries at their mouths) were filled from the main channel rather than aggraded by their own creeks.''[189]

If the Illinoian ice obstructed the lower course of the Wapsipinicon river valley then somewhere west of the present Mississippi river there must be evidence of a temporary Mississippi channel and such evidence is not lacking. A well defined valley follows the Wapsipinicon river valley east for about fifteen miles from the debouchure of Mud creek and in the other

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188 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, pp. 352-353, 1899.

189 Norton, W. H., Geology of Scott County: Iowa Geol. Survey, Vol. IX, p. 415, 1899.

direction it can be traced northward through Clinton and Jackson counties as far as Spragueville where it unites with the valley of the Maquoketa. In many respects this old valley, termed the Goose Lake channel and first described by McGee,[190] is similar to the one occupied by Mud and Elkhorn creeks. Both are occupied by two insignificant streams, one flowing to the north and the other to the south. In both cases, the streams occupy disproportionately large valleys. As the

FIG. 30.—View of Goose Lake Channel in Jackson county.

divide between Mud and Elkhorn creeks is imperceptible and ill drained, so too is the valley between the headwaters of the south-flowing Brophy creek and the north-flowing Deep creek. The divide between the two creeks is in sections 4 and 5 of Center township and 32 and 33 of Deep Creek township, Clinton county. Formerly a lake, Goose Lake, formed the head of Deep creek, but at the present time the site of the lake is represented by a large marsh. The streams that flow in the ancient valley occupy but mere trenches as they are very shallow and but a few feet wide. Goose Lake channel, figure 30, is far more pronounced than is Mud creek valley. Its valley walls,

190 McGee, W J, The Pleistocene History of Northeastern Iowa: U. S. Geol. Survey, Eleventh Ann. Rep't., Pt. I, p. 392, 1899; The Drainage Systems and Loess of Eastern Iowa, Private Publication, 1884.

especially in the northern half, are cut into bedrock and rise seventy to two hundred feet above the valley floor. Toward the south end of the valley the bluffs are only about twenty-five feet high. Exposures in the channel are extremely few. In section 34 of Center township, Clinton county, along the southeast bank of the creek several feet of horizontally stratified sand covered by two feet of loess is exposed. In the southeast corner of section 13, just north of Spragueville in Jackson county, a bed of laminated silts and sands several feet thick is exposed. Immediately north of Preston the south bank of the creek shows brown clay containing innumerable chert chips and pebbles. This clay, which is a foot to a foot and a half thick, overlies fine grained thinly bedded yellowish to brown

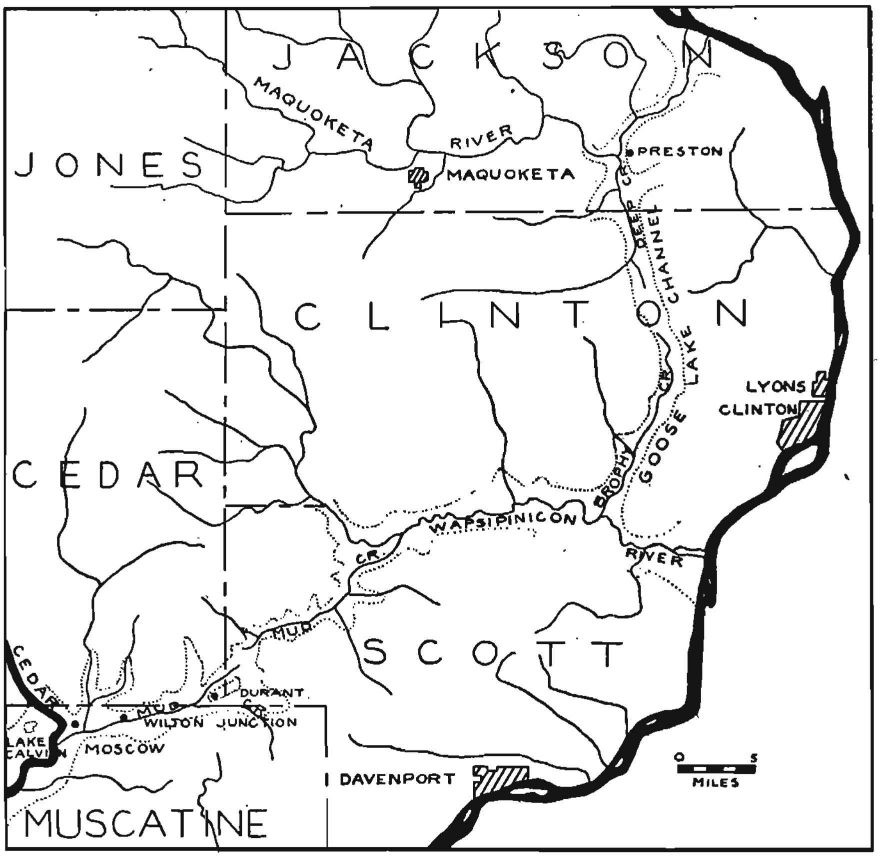

FIG. 31.—Map showing the course of Mississippi river north of the Lake Calvin basin during Illinoian times.

pebbleless sand. According to Carman "The surface material of Goose Lake valley passes downward into fine sand which is 60 to 100 feet thick on the divide south of Goose lake. Farther north in Secs. 17, 8 and 5 of Deep Creek township, Clinton county, several wells go to 110 to 120 feet in sand and fine gravel. In the south part of the channel south of Elvira wells 70 to 80 feet deep do not reach rock."[191]

The temporary Mississippi followed the rock bound gorge of Maquoketa river from the mouth of Deep creek to Mississippi river. The course of Mississippi river during the Illinoian times is shown on figure 31.

Interpretation.—The nature and structure of the silts and laminated clays exposed in Elkhorn valley in the vicinity of Wilton Junction practically preclude contemporaneous aggradation. As has been shown before, the terrace materials consist of fine horizontal laminated silts and clays without coarse sands, gravels or bowlders. It is practically impossible to assign such deposits to fluvial influence. The fine lamination of the deposits, which at places are over thirty feet thick, implies quiet water or lacustrine conditions. On the other hand, one might expect to find coarse sands and gravels, showing evidence of rapid deposition in the valley, if fluvial conditions existed, since the valley follows the edge of the Illinoian drift plain. Naturally here, nearest to the ice edge, we would expect the coarsest material to be laid down. Large bowlders are practically lacking from the terrace surface except those located by Udden[192] in sections 8 and 11 of Wilton township and in section 2 of Moscow township, Muscatine county. In speaking of these bowlders Udden states that they were "in all probability, transported by floating ice on the surface of the lake at an early stage, when the waters stood high, and were probably stranded on the shores."[193] To the investigator, the laminated silts and clays argue positively for lacustrine conditions.

The fact that a continuous valley, partly occupied by streams and partly abandoned, can be traced from the lake basin to

191 Carman, J. Ernest, The Mississippi Valley Between Savanna and Davenport: Illinois Geol. Survey, Bull. 13, p. 57, 1909.
192 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 354, 1899.
193 Idem, p. 354.

the Mississippi river by way of Maquoketa river strongly suggests the possibility of a lake. It has been shown that the Mud-Elkhorn valley is disproportionately wide and is not the product of the insignificant streams which occupy portions of it. Furthermore, the valley is distinctly traceable over two stream divides. A better inlet to the lake could not be desired.

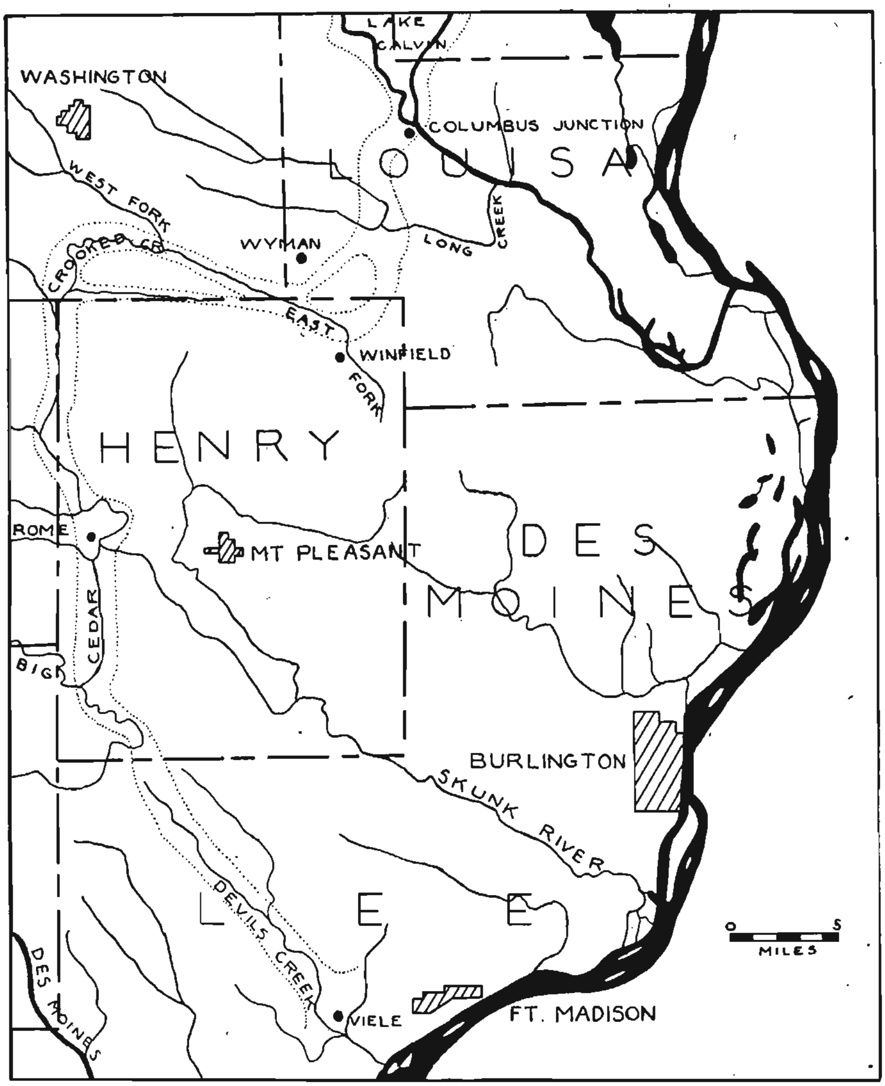

FIG. 32.—Map showing the course of Mississippi river south of the lake basin during Illinoian times.

THE TEMPORARY MISSISSIPPI CHANNEL OF LEVERETT.

Discussion.—The outlet is of still greater importance as a criterion of extinct glacial lakes. As early as 1896 Leverett discovered an abandoned channel between the Illinoian and Kansan uplands in Louisa county. This channel, which is outlined on figure 32, has been described in detail by Leverett in his monograph on the Illinois Glacial Lobe. The following description is taken from this report: "The course of the channel is southward from just above Columbus Junction to the vicinity of Winfield, a distance of 12 miles, crossing Long Creek, a small tributary of the Iowa, about six miles south of Columbus Junction . . . . . Before reaching Winfield a channel branches off to the west from the main channel and joins it again just south of Wyman. This channel has a breadth of but one-eighth mile or less. It is more direct than the main channel, and has about the same depth.

A short distance east of Winfield the main channel is entered from the east by the East Fork of Crooked Creek, and this stream meanders through the broad bottom of the main channel westward to its junction with the West Fork, and thence continues west and south to Skunk River Valley at Coppock. Another channel leads directly west from Winfield past Wayne to Coppock, a distance of 15 miles. The combined width of the two channels is but little greater than that of the portion of the channel north of Winfield, the channel along Crooked Creek being about three-fourths to one mile in width and the channel leading past Wayne one-fourth mile. The lower portion of Crooked Creek nearly occupies the full width of the north channel, but throughout the greater part of the course it is bordered by a broad terrace-like plain, several times the breadth of the valley which it has excavated . . . . .

The portion along Skunk river from Coppock to Rome, a distance of 10 miles, is so completely occupied by the valley of that river that only occasional narrow remnants of the abandoned channel appear as terraces on its borders, the average breadth of that part of Skunk River Valley being fully one mile. The most extensive remnant of the abandoned channel is found in the double ox-bow made by the river north and west of Rome, which stands, where not broken down by subsequent erosion, about 670 to 675 feet above tide.

From Rome the abandoned valley continues southward along the valley of Big Cedar Creek (reversed) and is preserved in terracelike remnants on each border of the valley which stands 30 feet or more below the level of the upland plain. The average breadth of the valley being not less than one-half mile the terrace remnants are narrow. From the bend of the Big Cedar, eight miles south of Rome, the old valley, as noted above, leads southeastward across Lee county to the Mississippi Valley at Viele, six miles below Fort Madison, gradually deepening from 30 feet to the north to 50 or 60 feet at the south. It is occupied for about 4 miles by Little Cedar Creek just south of the bend of Big Cedar. The remainder of its course is drained by Sugar Creek. The excavation along the channel from Columbus Junction to Viele is estimated to be one-half a cubic mile.''[194]

This ancient valley of the Mississippi is incised below the general upland surface of the Kansan drift plain thirty to sixty feet. The valley floor rises 120 feet above the level of Iowa river and in the vicinity of Columbus Junction it lies at an elevation of about 700 feet above sea level. Its general width ranges from one and one-quarter to one and one-half miles. The valley is well defined but is more conspicuous the farther southward it is traced. At the divide in sections 35 and 36 of Elm Grove township, Louisa county, seven miles south of Columbus Junction, the valley floor is one mile wide and thirty-five to forty feet below the general upland level. (See fig. 9, page 114.) Several miles south of Columbus Junction bedrock appears in the valley walls and that part along Skunk river is cut largely in solid rock. Unusual deposits of sand and gravel are lacking in the channel.

Interpretation.—The absence also of any notable deposits of sand or gravel in the temporary Mississippi river channel of Leverett seems to be in opposition to a fluvial hypothesis. If the filling up of the lake basin is due to stream deposition

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194 Leverett, F., The Illinois Glacial Lobe: U. S. Geol. Survey Monograph XXXVIII, pp. 91-93, 1899.

then there appears to be no logical reason why similar deposits as those found in the lake basin and in the Wilton Valley should not be seen in the abandoned Mississippi channel, the course pursued by the streams at the time of glaciation. The absence of such materials at once demands an explanation. There is no reason to believe that the streams were no longer overloaded by the time the waters used the channel nor that erosion has since removed the materials that may have been deposited. When it is remembered that a lake acts as a filtering plant for a river, it is easy to account for the absence of notable sand and gravel deposits in the abandoned valley if Lake Calvin existed and Leverett's channel served as its outlet. For comparison the streams emptying into and draining the Great Lakes may be cited. It is well known that the streams emptying into the Great Lakes are discolored and muddy because of the large amount of sediment which they carry. Also it is true that such streams as the Niagara and the St. Lawrence which drain away from the lakes are relatively clear and free from sediments and hence have little erosive power. Because of the filtration of sediments and perhaps also because "the ground in which this channel was excavated may have been frozen at the time of the Illinoian glaciation, its situation being on the immediate border of the ice sheet"[195] it is not to be expected that the outflowing stream would have much erosive power nor much material to deposit so that the absence of notable deposits of sand and gravel within the channel is quite the natural thing to be looked for. This too may explain why the abandoned channel of Leverett is not so well developed as the Mud-Elkhorn valley, especially that portion which is known as the Goose Lake channel. Leverett has traced the channel from the southern extremity of the lake basin at Columbus Junction across several counties to Mississippi river below Fort Madison. This channel furnishes an excellent outlet for Lake Calvin.

LAMINATED SILTS, CLAYS AND SANDS IN THE LAKE BASIN.

Discussion.—The finding of horizontally laminated clays or

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195 Leverett, F., The Illinois Glacial Lobe, U. S. Geol. Survey Monograph XXXVIII, p. 93, 1899.

silts is positive evidence of quiet water sedimentation and may be taken in most cases as indicating deep water deposits and lacustrine sediments. In general, it may be stated that the materials of the high and intermediate terraces are of low textural range and are finely stratified. Laminated silts or clays, however, are practically limited to the valley of Mud creek. Eight good outcrops of terrace materials are present in a distance of five miles, commencing one mile west of Wilton Junction and extending to a point four miles east of the town. As was mentioned in Chapter V under the discussion of the materials and structure of the Wilton Valley terrace, the eastern half of the valley shows a predominance of laminated silts and clays whereas in the west end fine stratified sands are more common. There can be no doubt that the deposits such as are represented by the typical section of terrace materials as given on page 159 (see fig. 25) were laid down under quiet water conditions. Practically thirty-four feet of laminated silt or clay is exposed in the type outcrop. Pebbles are entirely lacking and the stratification is horizontal and undisturbed except for a few minor wavy undulations. Other laminated deposits may be seen in the high terrace two and one-half miles east of Hills (see fig. 19, page 152), in sections 31, 32 and 36, Pleasant Valley township, Johnson county, and in sections 3 and 4 of Oakland township in Louisa county. Similar sediments are exposed in the intermediate terrace in section 8, Goshen township, Muscatine county. The exposed thicknesses of these deposits range from seven to twenty feet.

Interpretation.—The laminated silts and clays exposed in the terrace in the vicinity of Wilton Junction have been discussed. A study of the high and intermediate terrace materials shows that they consist principally of fine to medium-grained sands most of which are horizontally stratified. If these sediments are to be attributed to fluvial conditions, then the streams carried practically no coarse material, a condition hardly possible when one considers the enormous amount of material deposited and the vast area covered.

The structure of the sediments is even more detrimental to the theory of alluvial deposition than is their texture. It is difficult to account for the general horizontal stratification over such a wide extent as is found in the lake basin on the basis of stream deposition. In sharp contrast to the general horizontal stratification of the high terraces is the high cross-bedding of the sands and gravels of the low terrace. This terrace is without doubt of glacio-fluvial origin, as is evident from the nature of these deposits, from their texture and structure and from the fact that the low terrace can be traced to the Iowan drift plain. Is it possible that the Iowan ice sheet supplied coarser material than the Illinoian? Although it is possible, there appears to be no logical reason why it should have done so, especially since the Iowan ice sheet is believed to have been a thin glacier as is evidenced by the thin deposit of Iowan drift. Furthermore, the Iowan outwash materials were not laid down as directly in the lake basin as were the materials coming from the Illinoian ice sheet, which adjoined the lake basin.

It therefore appears that the nature of the sediments of the high, the intermediate and the Wilton Valley terraces demands another hypothesis than that of fluvial aggradation to account for their origin, especially since the known alluvial deposits as evidenced by their texture and structure are in striking contrast to those of the above mentioned terraces. On the other hand, the fineness of the deposits and the general horizontal stratification can well be accounted for by a lacustrine hypothesis.

TERRACES IN THE LAKE BASIN.

Discussion.—It is not evident whether a lake plain can be differentiated from a stream terrace on the basis of topography after dissection has progressed. The surface of the lake floor may be more level over a long distance or may have a lower gradient than that of an alluvial terrace, yet it does not follow that this need be the case. There are three distinct terraces in the lake basin, the high, the intermediate and the low, but what relationship exists between them is not apparent. The high and low terraces are in contact in numerous places in Johnson county and are separated by a well defined straight escarpment about thirty feet high. In Oakland township, Louisa county, and at West Liberty, the high and intermediate terraces join. The average vertical distance between the surfaces of these two terraces is thirty-five feet. As previously described the high and intermediate terraces are more or less gently sloping plains dotted with numerous sand dunes, an exception to this being the one in Wilton Valley. In contrast to these are the low terrace and the present flood plain of the rivers, which are practically free from sand dunes.

From a study of elevations as given on page 116, it is seen that the high terrace is closely related to the Wilton Valley terrace as well as to the one northwest of West Liberty. It is evident from a comparative study of their materials and structure, as well as of their elevations, that the low terrace in Johnson county is not represented by the intermediate terrace in Muscatine county. The low terrace is of fluvial origin as it is composed of Iowan outwash materials. From the descriptions of the materials given in the previous chapter, it is seen that the high and intermediate terrace deposits are much finer and the textural range is much lower than those of the low terrace. Furthermore, the stratification is, on the whole, more horizontal and less disturbed. An excellent comparison of terrace materials of the high and low terraces is to be had in two outcrops one mile and two and one-half miles east of Hills in Johnson county. The location of the two exposures is indicated in the following sketch map.

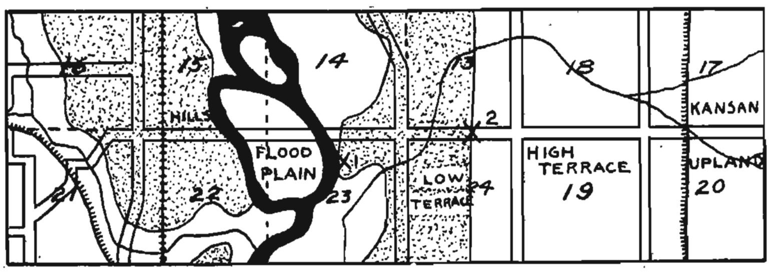

FIG. 33.—Sketch map showing location of two typical outcrops; 1, alluvial; 2, lacustrine.

Exposure 1 is in the low terrace and exposure 2 is in the high terrace. Whereas the material of the high terrace is extremely fine sand or silt, horizontally bedded, the material of the low terrace consists entirely of a fine to medium-grained, white to gray and brown heterogeneous sand containing numerous pebbles and having a medium textural range. Most of the sand is cross-bedded with cross dip at angles ranging from twenty to thirty degrees. Although in general the cross-bedding dips in a southerly direction, the direction of dip at any particular place is not necessarily consistent with the general dip. The gravel layers not only dip in all directions but they pinch out in short distances. In short, the structure of the deposit shows typical cross-bedding and pocket-and-lens type of structure. This deposit, twenty-one feet thick, is in sharp contrast with the other outcrop only one mile farther to the east where cross-bedding, pocket-and-lens type of structure and varying texture of materials are replaced by horizontal stratification and sediments of extremely low textural range and uniform composition. The conditions under which these two deposits were laid down are obviously not the same.

The slope of the high terrace appears to be gentler than that of the intermediate terrace. From the elevations obtained, the gradient of the former terrace is found to be one and four-tenths of a foot per mile, whereas the latter has a gradient of two and one-half feet per mile. However, the writer is inclined not to place much importance on the gradient of the high terrace, as barometric readings had to be used in its calculation. The gradient of the Wilton Valley terrace, one foot per mile, compares favorably with that of the high terrace. When a comparison is made of materials, texture and structure between either the high, the Wilton Valley or the intermediate terraces and the low terrace, it is apparent that the conditions under which they were formed were different.

Interpretation.—Many hypotheses may be advanced to account for the origin of three distinct terraces, depending upon whether they are all of different ages or whether some two or all three are contemporaneous. Before discussing any hypothesis, it will be well to see what relationship exists among them. The problem is somewhat complicated since the low and the high terraces are confined to the Iowa river arm of the lake basin and the intermediate terrace is limited to the Cedar river arm.

It has been shown previously that the high terrace, the terrace north and northwest of West Liberty and the Wilton Valley terraces had a common mode of origin. The questions now to be settled are

1. Are the high and intermediate terraces of the same age or do they represent two stages of terrace development?
2. Are the low and intermediate terraces contemporaneous in origin?

ARE THE HIGH AND INTERMEDIATE TERRACES OF THE SAME AGE OR DO THEY REPRESENT TWO STAGES OF TERRACE DEVELOPMENT?

A study of elevations, materials and structure of the high terrace and the Wilton Valley terrace shows that the two are closely related and undoubtedly are of the same age. The intermediate terrace lies at a lower elevation than the other two terraces, but is very similar to them in so far as materials and structure are concerned, although it differs in all three respects very strikingly from the low terrace. The question arises: Is the intermediate terrace contemporaneous in origin with the high terraces? If so, why the difference in elevation? All things being equal, the filling of a lake ought to be uniform and hence but one set of terraces should be expected to represent the ancient lake bed. However, in a case like that of ancient Lake Calvin where the lake if it existed consisted of two arms and where the supply of sediments coming into the lake was determined by the number and size of the inflowing streams, the lake floor need not necessarily have the same elevation in the two arms. To account for the difference in elevation between the high and intermediate terraces several hypotheses may be presented. The original slope of the valley walls and the depth of the valleys may have been an influencing factor in determining the height of the lake bed at various places. Under similar conditions of sedimentation, the bed of Lake Calvin ought to be uniform and have the same elevation in the two arms of the lake, provided that the depth of the valleys was the same. However, if the depth of the two arms differed or if the slope of the valley walls was different as is indicated in the following diagram, a difference in the elevation of the two lake floors might be possible. In a case such as is indicated by the diagram, figure 34, all things being equal, an equal amount of sediment would necessarily mean a higher lake bed in that portion of the lake occupying the shallower valley and having the gentler slope. The high terrace is confined practically to the eastern part of the western or Iowa river arm of the lake basin whereas the intermediate terrace occupies the eastern or Cedar river arm of the lake site. The bluffs adjacent to the intermediate terrace are very distinct, steep and sharply defined, whereas those forming the high terrace are less well outlined, due to the gradation between bluffs and terrace. Practically everywhere south of the latitude of Hills, the impression gained while standing on the terrace is that the Kansan upland slopes gradually toward the south and southwest and is covered by a veneer of finer sediments. The topography of the terrace is gently undulating, suggesting that the sediments composing the terrace materials were deposited in more or less shallow water, probably forming bars and beaches. The sand from these bars and beaches probably was formed into sand dunes which encroached upon the bluffs and thus caused them to be less well outlined.

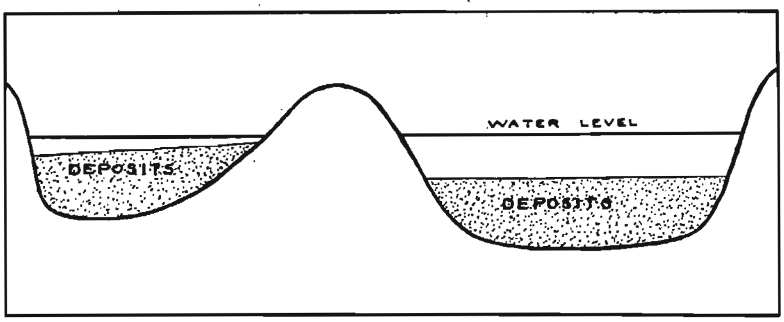

FIG. 34.—Diagram showing how the depth and the slope of the lake bed may result in different elevations of the lake floor, the amount of material being equal.

Another factor entering into the problem of the difference in elevation between the high and intermediate terraces is the number of streams emptying into the lake basin. A glance at Plate VIII shows at once that the Iowa river arm of the lake basin receives not only the greater number of affluents but also the larger ones. Since it receives larger and more tributaries, this portion of the lake naturally should receive the greater amount of sediment, a fact which seems to be borne out by the presence of the high terrace in this portion of the lake basin. The Cedar river arm of the lake basin receives practically no streams of any significance. The largest streams emptying into this portion of the lake basin are confined to the north end. In the northwest corner is Wapsinonoc creek with its two branches. Here also the terrace is higher than the intermediate terrace. In the Wilton Valley also, the terrace is higher than the intermediate terrace due undoubtedly to the fact that deposition took place there first as the valley formed the northeastern extension of the lake. The westward extension of this high terrace may have been hindered by Cedar river destroying it as quickly as the terrace was built up. On the other hand, an extension of the Wilton Valley terrace westward may have caused Cedar river to be dammed up more than the lake basin itself. Such a ponding of the river may have resulted in a lake being formed over the area to the east of the river, an area which has a topography quite unlike the ordinary Kansan. The region is essentially flat and is covered to a large extent by sand dunes. The age of this youthful-appearing supposedly Kansan area has been questioned by Leighton.[196] May it be Illinoian, or a former lake site, or is it a rock terrace covered with a veneer of Kansan drift? The problem still remains open.

A difference in the depth of the two arms of the lake basin and in the slopes of their floors, together with a greater supply of sediments to certain portions of the basin readily explains the different elevations of the lake bed. Thus, on the supposition that Lake Calvin existed, the high and intermediate terraces may be considered as having been formed contemporaneously. If the two terraces were formed at the same time should not the intermediate terrace be less cross-bedded than the high terrace and be made up of finer materials? Study of the terrace materials shows that the part of the high terrace south of River Junction is cross-bedded, due to the fact that the largest tributary, English river, emptied into the lake basin at that point. The terrace materials north of River Junction are finer and less cross-bedded because Old Mans creek

196 Personal communication.

and Clear creek are smaller and thus were not able to carry such coarse materials as English river carried. However, but few sections were seen in the upper part of the high terrace. New exposures may reveal cross-bedding and coarser materials.

DO THE HIGH AND INTERMEDIATE TERRACES REPRESENT TWO STAGES OF TERRACE DEVELOPMENT?

The question may be asked: On the supposition of a lake hypothesis, do the high and intermediate terraces represent two stages of terrace development? Is there any evidence indicating that Lake Calvin had two stages? Udden in discussing certain bowlders in the lake region, accounts for them as having been transported in all probability "by floating ice on the surface of the lake at an early stage, when its waters stood high."[197] Again, the same writer states "The high stage of the lake must, however, have been of short duration, for the bowlders are few and not associated with any indications of a shoreline. It may indeed have been of the nature of a periodic or an accidental overflow."[198] The above evidence does not prove the formation of any one of the terraces in the lake basin. Lake Calvin, if it existed, occupied the lake basin for a considerable time, probably until the coming on of the Iowan ice sheet. On the basis that the lake existed far into the Sangamon interglacial interval, the intermediate terrace may be explained as consisting of the first sediments laid down in the lake. This may account for the fact that the intermediate terrace contains the coarser materials of the two. Most of the deposits and those of the coarsest character naturally would be deposited in the early stages of the lake's history, especially while the ice sheet still occupied the region. As time elapsed and the glacier had retreated from the region, finer and finer as well as fewer materials were brought to the lake. These later deposits may constitute the sediments of the high terraces which are built out as deltas into the lake. It is a noteworthy fact that the high terraces are located wherever streams empty

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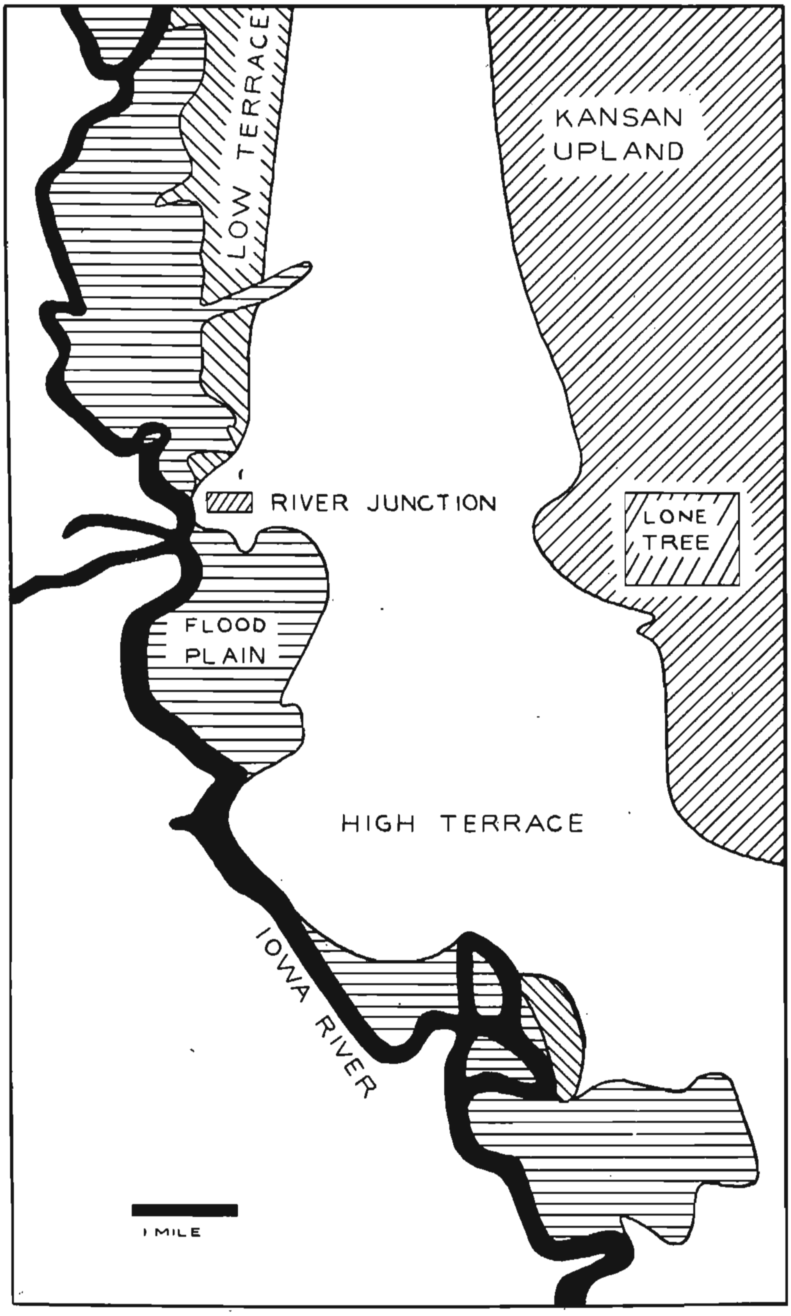
197 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 354, 1899.
198 Idem, p. 355.

into the lake basin at the present time. In that case the high and intermediate terraces will still have to be considered as having been formed contemporaneously.

The theory that the high terraces represent the lake's history during the time when the outlet of the lake was by way of the now abandoned Mississippi channel of Leverett and that the intermediate terrace represents the period when the waters of Lake Calvin escaped by way of the Iowa-Cedar river valley seems to have little weight. The intermediate terrace is by far the most widespread and, judging from several well records, undoubtedly has the greatest thickness of sediments. Hence, all things being equal, the formation of this terrace should involve a greater length of time than that of the other terraces. Furthermore, the greatest amount of deposition should have taken place during the earlier stages of the lake's existence. Indications, however, point in other directions. The straight line of contact between the high and low terraces suggests that the lake's outlet was by way of the now abandoned channel until the advent of the Iowan ice. This unusual line of contact seems to indicate that in the formation of the high terrace the stream did not meander and hence did not exist very long. It appears as if the terrace was eroded rapidly, or why the absence of the sinuous outline which it has where the flood plain of the present river abuts against it? (See Plate XIV.) To account for the remarkable line of contact between the two terraces, the following hypothesis is offered. Lake Calvin remained for an exceedingly long time after the ice sheet had retreated from the region. Its water level must have stood as high as the lowest point in the now abandoned channel which served as its outlet until the new outlet by way of the Iowa-Cedar river valley was formed. The formation of the new outlet must have taken place near the time of the advent of the Iowan ice and the lake must have been drained in a comparatively short time. This seems to be indicated by the fact that the river to which the formation of the high terrace may be attributed did not have time to reach maturity and meander and develop such a sinuous escarpment as the terraces bordering the present Iowa and Cedar rivers have. While the stream



Map showing the difference in the escarpment of the high terrace where it is in contact with the low terrace and with the flood plain.

was still in the early stages of forming the high terrace, the Iowan ice sheet invaded the region to the north. As a result of this ice incursion, the stream was changed from an eroding to an aggrading river due to the overloading of the stream with sediment coming from a new source of supply. Thus a new flood plain was developed. As soon as the ice had retreated and the supply of sediment was cut off the stream found itself above grade and immediately began to cut down its bed again, thus giving rise to the formation of the low terrace, part of which has been removed since. Sufficient time has not elapsed for the removal of all of the low terrace, hence the straight escarpment of the high terrace persists where the two are still present and are contiguous. The irregular escarpment of the high terrace is found only at those places where the river has removed the low terrace and has cut into the high terrace.

Another factor bearing upon the problem of the length of time that Lake Calvin was drained by way of Leverett's channel is that of the Illinoian gumbotil. If present contentions are correct, the formation of a gumbotil is an exceedingly slow process and implies little or no erosion. The Illinoian gumbotil is at least five feet thick and was formed before Lake Calvin could have been drained by any other outlet than the now abandoned channel south of Columbus Junction. Illinoian gumbotil outcrops along both sides of the Iowa-Cedar and Mississippi rivers. If our present ideas of the formation of the gumbotil are correct, then the lake could not have found its discharge by way of those valleys. The gumbotil then is in perfect harmony with the straight escarpment between the high and low terraces as vouching for a long life history of Lake Calvin.

Thus so far all indications point to the view that the intermediate terrace does not represent a stage in the existence of the lake when it was drained by way of the Iowa-Cedar river valley.

It can not be argued convincingly that the high terrace in the Cedar river arm of the lake basin was ever more widespread than it is now. As long as the outlet of Lake Calvin was south of Columbus Junction, a lake existed and erosion of the terrace was out of the question. The theory that erosion since the lake was drained has removed most of the high terrace does not seem sound. In the first place, why should not more of the high terrace in the Iowa river arm of the lake have been removed since that time? Then too, field relations do not warrant such a supposition.

It therefore appears to the writer that there is no way of escape from the conclusion that the high and intermediate terrace are contemporaneous in origin. Therefore they must be lacustrine, as exact contemporaniety is impossible on the basis of a fluvial hypothesis.

ARE THE LOW AND INTERMEDIATE TERRACES CONTEMPORANEOUS?

The establishing of the contemporaneity or of two distinct ages of the intermediate and low terraces can readily be done from a study of the terrace materials irrespective of either the lacustrine or the fluvial hypotheses. The low terrace is confined to the Iowa river section of the lake basin whereas the intermediate terrace lies practically all in Muscatine county. At no place are the two contiguous. A comparison of elevations of the two terraces at places having the same latitude shows that the intermediate terrace is ten to twenty-five feet higher than the low terrace as may be seen from the following table. However, a difference in elevation does not in itself disprove contemporaneity of origin. A study of terrace mater-

LATITUDE OF	LOW TERRACE ELEVATION	INTERMEDIATE TERRACE	DIFFERENCE IN ELEVATION
	Feet	*Feet*	*Feet*
Hills	640	665	25
Iowa Junction	628	638	10

ials, including their texture, stratification and structures, is the more important factor in determining whether the low and intermediate terraces had a common mode of origin. As shown in Chapter V, and on subsequent pages, the materials in the low terrace have a high textural range, are highly cross-bedded, show pocket-and-lens type of structure, in short show typical characteristics of fluvial deposits. On the other hand, the intermediate terrace is made up in the main of deposits having a low textural range, the stratification is, as a rule, fine and horizontal and the pocket-and-lens type of structure is inconspicuous if not entirely wanting. Considered on the basis of deposits alone, the terraces are undoubtedly not of the same origin. Furthermore, the fact that the terraces do not have the same elevation at places of the same latitude materially strengthens the foregoing conclusion.

Summing up what has been said so far regarding the three terraces, it is seen that on the basis of a lacustrine hypothesis the high and intermediate terraces are of the same age and the low terrace is not contemporaneous with the intermediate, thus reducing the set of terraces down to two. According to the fluvial hypothesis, there are three terraces of three distinct ages to be accounted for.

Since a study of terrace materials shows that the low terrace is positively fluvial or glacio-fluvial and is Iowan in age, since the other two terraces are quite unlike the former and can very readily be correlated in age under the lacustrine hypothesis, and since most of the other features of the lake basin can not be explained as well on the fluvial as on the lake hypothesis, there is no need for further discussion of the terraces.

A combination of the fluvio-lacustrine type of hypothesis has not been presented because of the readiness with which all features can be explained on the basis of a lacustrine interpretation.

ROUNDED BLUFF LINES OF THE LAKE BASIN.

Discussion.—Relative straightness and smoothly curving or rounded outline at places of indentations are the two striking features of the bluff line in the lake basin. A straighter line of bluffs than those marking the limits of the Illinoian upland can not be asked for. A comparison of the Illinoian bluffs in the lake basin and in the Iowa-Cedar river valley as shown on figure 35 brings out the fact that the former are far more regular than the latter. The valley along Iowa-Cedar river undoubtedly owes its origin to stream erosion. Does the straightness of the line of bluffs in the lake basin then argue for a different mode of origin? If not, why the difference in the

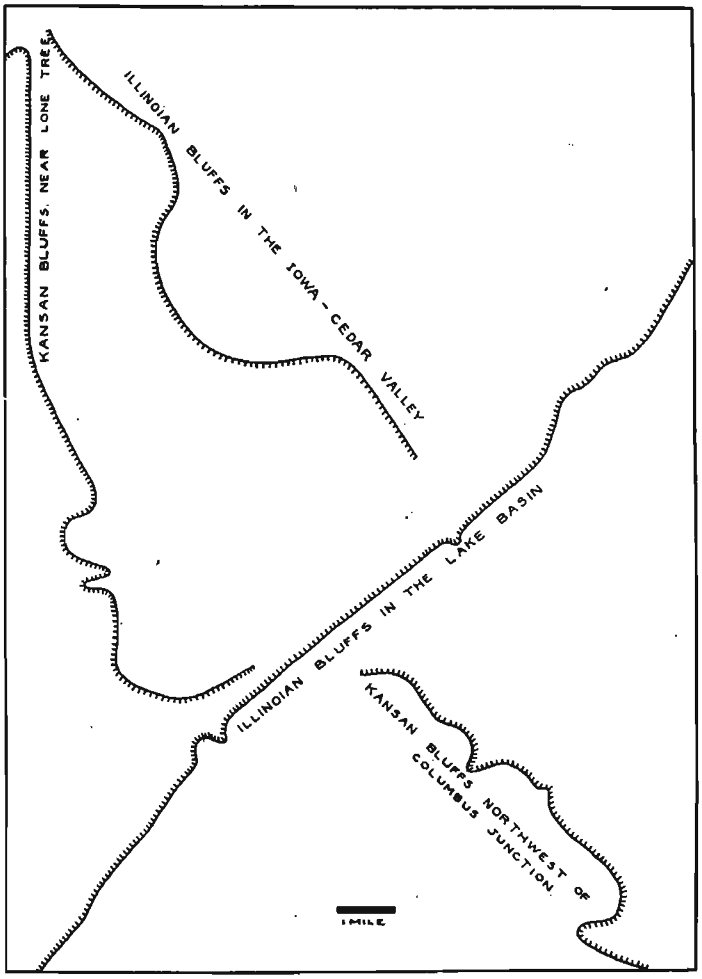
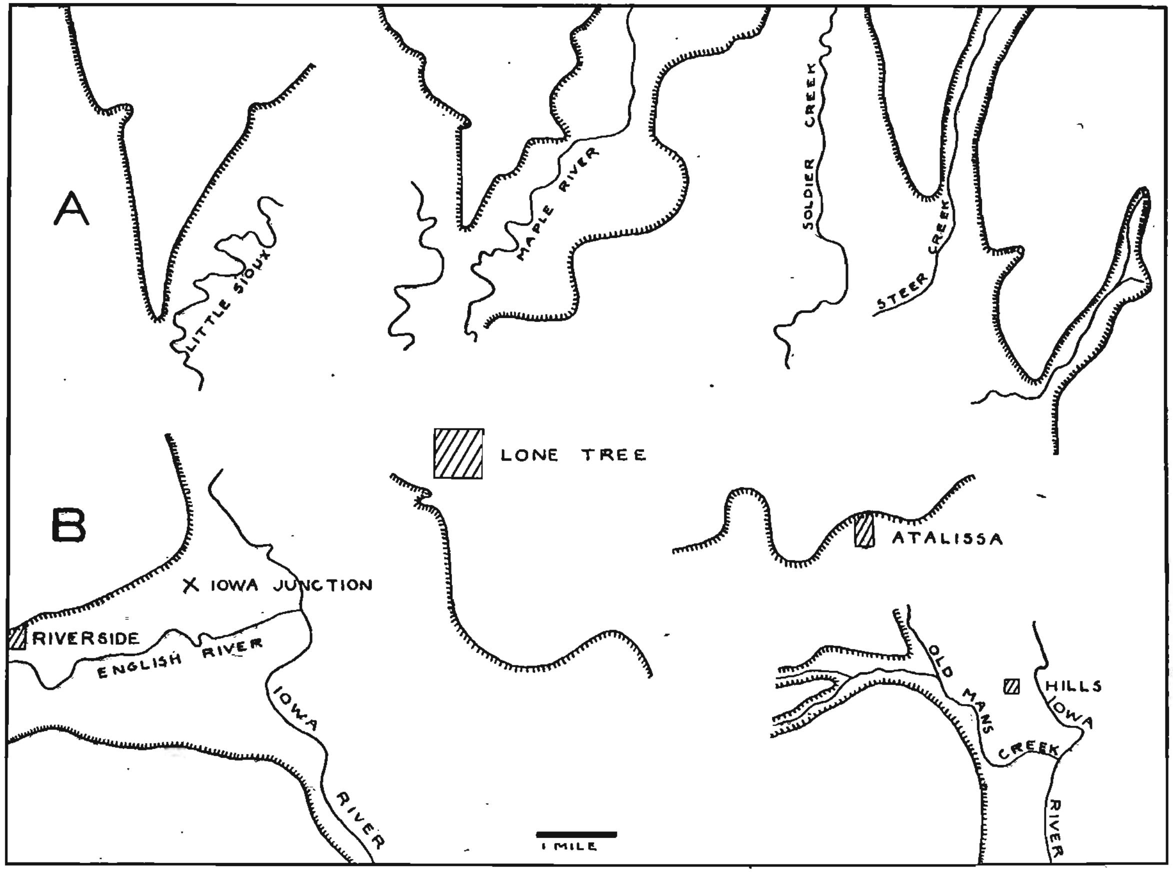


FIG. 35.—Comparison of bluff lines in the Lake Calvin region.

straightness of the bluff lines although both are cut into similar materials?

Normally at the junctions of stream valleys projecting spurs are found, such as are illustrated in A of Plate XV. A study, however, of the bluff line in the lake basin at places where two valleys meet brings out the fact that the normal type of projecting spur is missing but is replaced by very broad curves or rounded bluff lines. Granting that in exceptional cases such a bluff line may be developed by stream erosion, nevertheless



Diagrams showing the type of spur developed at the junctio n of two normal stream valleys in Harrison and Monona counties, A, and in the Lake Calvin basin, B.

it will also have to be admitted that when in the majority of cases the normal type of spur is replaced by the rounded form of bluffs, some other explanation than ordinary stream erosion will have to be sought to account for the abnormal conditions.

Interpretation.—A line of bluffs such as those of the Illinoian upland does not appear to be in harmony with the work of streams. Even on the supposition that the river was overloaded and therefore was aggrading its valley, the meandering of the stream must have caused it to cut into the bluffs somewhat and to erode them by lateral planation, thus giving rise

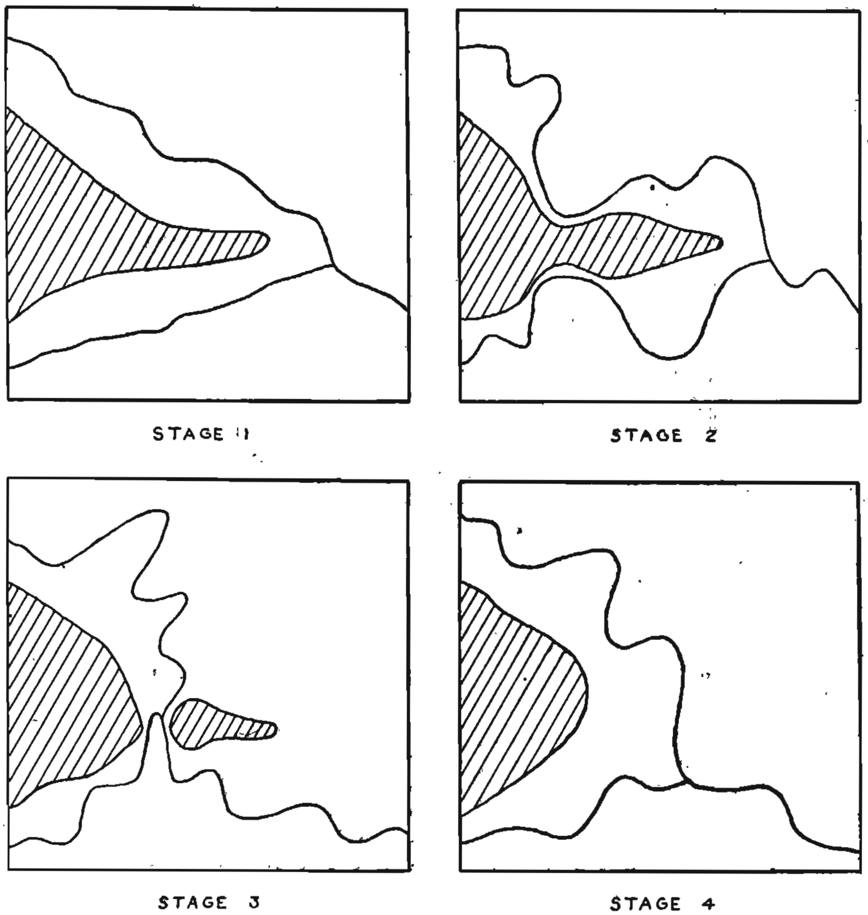


FIG. 36.—Diagrams showing the development of a rounded bluff line at the junction of two streams by the meandering of the rivers and the involving of stream piracy.

to a river-scarred type of valley wall. However, all traces of such a valley wall are lacking.

Perhaps the most difficult feature to account for is the characteristic and striking rounded bluff line found at the junction of two valleys, (See PlateXV.) The absence of the normal type of projecting spur in the lake basin very strongly indicates that other agencies than running water carved out the bluffs. A single case of a rounded bluff line at the junction of two valleys may be conceived of as having been formed by the action of running water due either to the meandering of the streams followed by piracy or to the development of tributaries and piracy. A case illustrating the latter method in the process of development is shown at Capitol Hill at Des Moines, Iowa, (See figs. 44-46, Iowa Geol. Survey, Vol. XXV, pp. 539-541, 1914.) A rounded bluff due to the former method is shown by the diagrams on figure 36. But when the majority of bluffs at the junctions of streams show broad curves, the hypothesis of

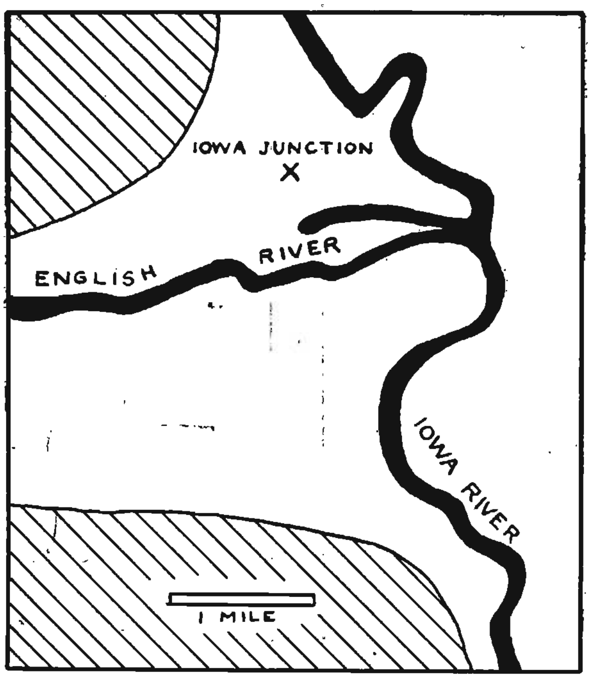


FIG. 37.—Sketch map showing the rounded bluff lines on both sides of English river.

stream work has to be abandoned. Furthermore, when the bluffs on either side of the river, as illustrated in the preceding diagram, figure 37, are of the rounded type, the idea of stream work as the agent loses much of its significance.

A more likely explanation for the abnormal type of bluffs in the lake basin is in the action of waves. There is no better force than the constant beating of the waves on the bluffs from all sides to explain their rounded character. Lakes never show characteristic sharp erosional headlands but rather features of well rounded outline. To the writer, the broad curving type of bluff line amounts to practically positive proof of the former existence of a lake in the lake basin.

BOWLDERS IN THE LAKE BASIN.

Discussion.—Bowlders are extremely few anywhere within the borders of the lake basin. The following is a list of locations where bowlders are found.

Louisa county

1. Oakland township, Sw.¼ Sw.¼ sec. 11, base of terrace.
2. Oakland township, Sw.¼ Nw.¼ sec. 15, top of terrace.
3. Oakland township south central edge of sec. 9, base and top of terrace.
4. Concord township, Ne. corner sec. 7, base and slope of terrace.

Muscatine county

5. Pike township, Ne. corner of sec. 7, top of terrace.
6. Goshen township, central part Sw.¼ sec. 34, top of terrace.
7. Pike township, Ne.¼ sec. 3, slope of terrace.
8. Pike township, Nw. corner Ne.¼ sec. 3, slope and base of terrace.

Except for localities 1, 2 and 3 the bowlders are within four and one-half miles of the Illinoian bluff line and the greatest number and the largest are found but half a mile distant from these bluffs. Bowlders at 1, 2 and 3 are from seven to eight and one-half miles from the same bluff line. The bowlders are mainly of the granitic type, although two are limestone and one is greenstone. They range in size from those having dimensions of 1.5x1.5x.5 feet to those having dimensions of 3.5x3x2 feet. In every case, the bowlders are associated with the intermediate terrace and lie either on its surface, as do those at 3, 5, 6 and 7; or on its escarpment slope, as is the case at 2, 4, 7 and 8, or else at its base, as in the case of those at 1, 3, 4 and 8.

Several possibilties present themselves as to the way by which these bowlders may have been brought to their position and location. These are summarized as follows:

1. Alluvial material.
2. Outwash from the Illinoian ice.
3. Ice-rafted bowlders floating down a stream.
4. Ice-rafted bowlders floating on a lake.
5. These bowlders may be from the original till underlying the lake basin; they mark places where the till outcrops now.
6. Some may have been carried in by man.

Interpretation.—Of the six methods summarized to account for the position and location of the bowlders in the lake basin, the first, fifth and sixth may be set aside after brief consideration. That the bowlders do not owe their position and location to ordinary fluvial conditions seems to be apparent when one considers the juxtaposition of the few large and scattered bowlders to the fine materials of the terraces. If the streams were able to transport a few bowlders from those a foot in diameter to those three feet in diameter then gravel could also have been transported easily and should therefore be in evidence among the terrace materials. However, gravel is not to be found and thus the finding of scattered bowlders on fine sands demands another hypothesis than that of ordinary alluvial conditions. That the bowlders are not the outcropping of an underlying till is clearly proved in most cases by the fact that many of them lie on the surface or slope of the terrace which is known to consist of stratified materials. In cases where the bowlders lie at the base of the terrace, it is not so apparent whether they are or are not to be considered as outcrops of till. At several places, as where the shingle-like gravels are found, the till lies but thirty feet or so beneath the terrace surface. On the other hand, records of wells at other places show a depth of over 250 feet of sands and gravels before the till is reached. Unfortunately well records in the lake basin are few and scattered.

With the exceptions of those at localities 5 and 6, there seems to be no logical reason why the bowlders should have been brought by man. A limestone bowlder was found at each of localities 5 and 6. In each case, the bowlder was found near a fence on the terrace surface. These two bowlders may have been brought in by man. However, at other places, the bowlders lie in such locations that artificial transportation is extremely unlikely.

The fact that the largest bowlders are found nearest to the bluff line and the smaller ones farther away suggests Illinoian outwash deposits. Yet the absence of other coarse material as well as the lack of structure typical of rapid deposition is not in harmony with an outwash hypothesis. The bowlders are best explained as being ice-rafted bowlders floating either down a river or on a lake, and as reaching their present position by the melting and the stranding of the icebergs. From what has been said before regarding the terrace materials and from the fact that many of the bowlders lie on the surface or slope of the terrace, which consists of fine to medium-textured, and for the most part horizontally stratified sand, it is easier to account for the bowlders as being brought to their final resting place by debris-laden icebergs floating on a lake than by any other method.

CERTAIN GRAVEL DEPOSITS IN THE LAKE BASIN.

Discussion.—Gravels are exposed at numerous places along the course of Iowa river. These gravels rest on a bluish to black till in practically every case and consist of rocks of all descriptions and sizes. There is no doubt that the gravels are closely related to the till and remain as distinct deposits because the finer mud or silt has been carried away. The noteworthy fact regarding these deposits is that an unusual number of the gravels and bowlders are flat or slablike rather than subangular as is characteristic of ordinary glacial material, or rounded, as are typical fluvial deposits. This shingle-like form is not limited to the softer sandstone and limestone but is common also to the more resistant varieties of rocks as cherts, granites, basalts, etc., and to rocks of all sizes from those an inch to two in diameter to bowlders measuring over a foot. It is important to remark in this connection that wherever these shingle-like gravels appear, the bluff line of the drift uplands is very close at hand. In no case is the bluff line more than one mile distant from the gravels. Gravels having the typical shingle-like character are found at the following places:

1. Washington county, Iowa township, sec. 23; half a mile from bluffs.
2. Johnson county, Fremont township, sec. 24; half a mile from bluffs.
3. Johnson county, Fremont township, sec. 25; half a mile from bluffs.
4. Johnson county, West Lucas township, sec. 34; a quarter of a mile from bluffs.
5. Johnson county, East Lucas township, sec. 27; one mile from bluffs.
6. Johnson county, Liberty township, sec. 27; one mile from bluffs.

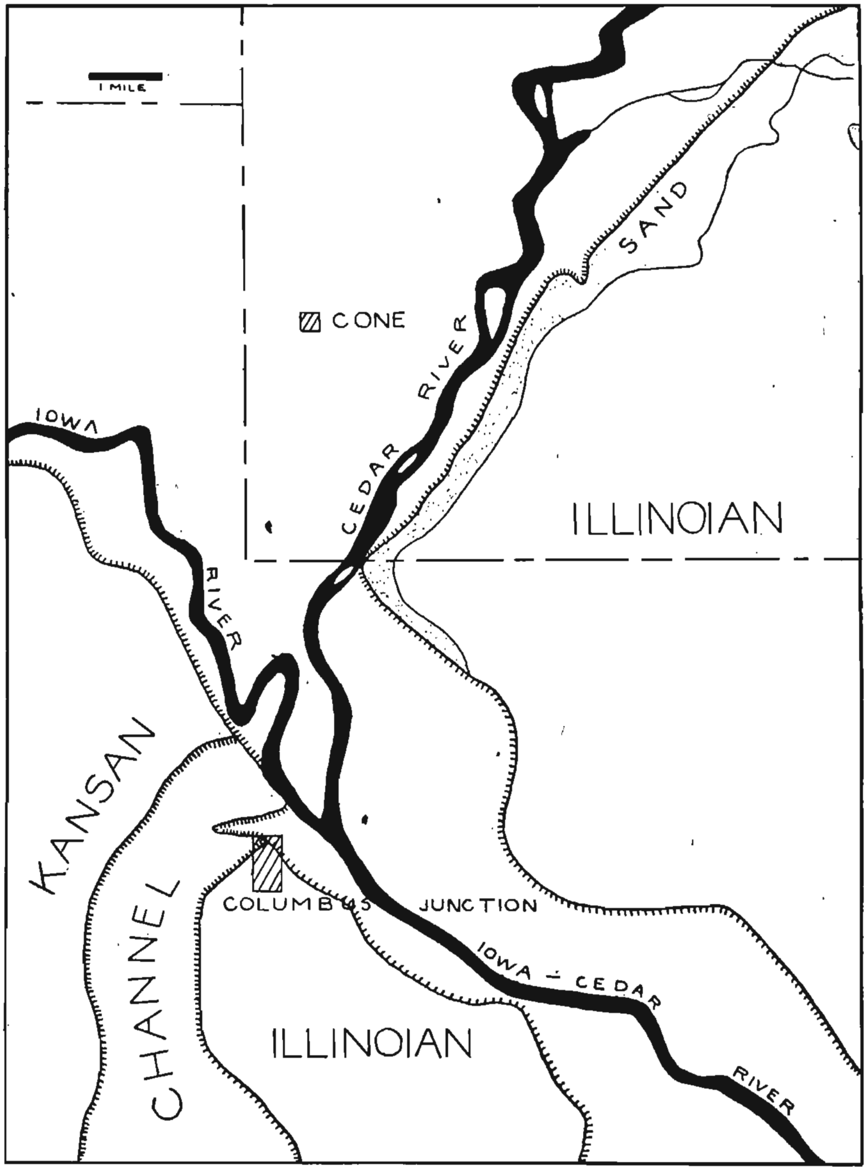
The shingle which is exposed in the abandoned railroad gravel pit in the southwest quarter of section 34, West Lucas township, Johnson county, does not rest on till but is interstratified between two sands of the low or Iowan terrace. The gravel bed is twelve to twenty-four inches thick and consists principally of limestone. The pieces range texturally from small sand grains to bowlderets nine by six by four inches. The slablike form, however, is not confined to the limestones, but is found also on the cherts and basalts. The Kansan bluffs are but a quarter of a mile to the west. According to the owner of the land in which the pit is located, the gravels underlie a large part of the low terrace. Evidently in this case the gravels attained their characteristic form before reaching their present position.

Interpretation.—It is a well known fact that in many cases gravels found along lake beaches or sea coasts possess a slablike form and show an arrangement similar to that of shingles on a roof, from which fact the deposits have received the term 'shingle'. From the fact that the gravels under discussion are of this type, and that the shingle character is not confined to any one kind of rock, but is common to all, whether they are resistant or nonresistant, igneous or sedimentary, and from the fact that the deposits appear to be related to the underlying till or the nearby bluffs, the writer feels inclined to explain the characteristic form of the gravels by the continued washing upon them of the waves. The shingle-like gravels interstratified between the sands in the low terrace in section 34, West Lucas township, Johnson county, undoubtedly were rehandled and brought to their present position by the action of glacial streams at the time of the Iowan stage of glaciation.

THE ILLINOIAN UPLAND WITHIN AND WITHOUT THE LAKE BASIN.

Discussion.—One of the noticeable features of the Illinoian upland is its sandy and dune covered border in the lake basin and the absence of such sandy deposits south of Columbus Junction and in the Mud-Elkhorn valley. This feature is the more striking because of the abrupt termination of the sandy tract south and east of the lake basin. (See Plate XVI.) A fringe of undulating sand dunes extends all along the bluffs from Mosquito creek in Moscow township, Muscatine county, almost to Columbus Junction in Louisa county. These sandy tracts are on the average less than half a mile wide, but reach a width of a mile or two miles at places, as two to three miles north of Bayfield. The dunes range in height from ten to fifty feet. The question at once arises: Why should there be a difference in the character of the bluff line east and south of the lake basin if conditions were the same? If no lake existed, but a river, why should there be a restricted area of sand? On the other hand, if Mud creek valley was the inlet to the lake and the outlet was south of Columbus Junction bordering the Illinoian upland, might there not be a difference in the character of the bluff line at these places as compared with the intervening Illinoian border which formed the shore line of the lake?

Interpretation.—On the basis of the theory that the filling of the lake basin is alluvium, there appears to be no good reason why the sandy tract should be restricted to the Illinoian bor-



Map showing the abrupt disappearance of sand dunes along the Illinoian upland border south of the lake basin.

der adjacent to the lake basin and abruptly terminate at Columbus Junction and be absent in the Wilton Valley. If a stream occupied the Wilton Valley, the lake basin and the temporary Mississippi channel of Leverett, then the entire Illinoian border adjacent to these places ought to be similar. Yet this is not the case as Plate XVI shows. On the other hand, if a lake occupied the area to the west of the Illinoian sand covered margin and the Wilton Valley and a stream flowed in the now abandoned channel, then it becomes a relatively easy matter to account for the difference in the bluff border. It is but natural that along the shores of a lake sandy beaches are thrown up. The sand on becoming dry becomes the prey of the wind which soon drives the sand into dunes. Sand dunes are not common along the courses of streams especially where these streams occupy the entire valley. If a lake existed in the region then the stream draining the lake would naturally be relatively free from sediment and also would have minimum erosive power to collect material for the formation of sand dunes. The absence of the dunes in the Wilton Valley, which probably was the site of a lake rather than of a river, may be accounted for by the facts that its longer axis is in the same direction as that of the prevailing winds, that the lake at this place was narrow and thus not well adapted for the formation of large waves and that the valley is not exposed as much as the lake basin proper. Thus all things considered, the writer prefers to explain the difference in the character of the Illinoian bluff line on a lacustrine basis.

A COMPARISON OF THE WIDTH OF THE VALLEYS IN AND OUTSIDE OF THE LAKE BASIN.

Discussion.—A study of the width of either the Iowa or the Cedar river valleys within and without the lake basin reveals the fact that the width of the valleys within the lake basin greatly exceeds that without. At various places the valleys outside of the lake basin are wide, not so wide, however, that they can not be accounted for by stream work. With the exception of one locality the width of the valleys outside the lake basin is nowhere one-half as great as that within the basin.

The Iowa-Cedar river valley in the vicinity of Wapello, where the valley is known as the Wapello prairie, has an unusual width. At Wapello it is six miles wide and for a distance of about five miles on either side of the town the valley is unusually well developed. The cause for this abnormal width has not been investigated.

Interpretation.—Why such a vast difference in the width of the valleys within and without the lake basin should exist if they are due to stream work is not easy to see. This is especially true since the valleys are cut into similar materials. The valley of Iowa river west of Curtiss, Johnson county, is unusually wide, although it in no way compares with the valley south of Iowa City and yet in both places the valley is cut into drift. It is easier for the writer to think of the valleys of Iowa and Cedar rivers within the lake basin as being of lacustrine origin rather than of fluvial origin.

CONCLUSIONS.

In order to sum up the various interpretations presented and before making any conclusions, the following table is introduced to show what hypothesis is favored by the interpretation of the various features found in the lake basin.

TABLE 3. TABLE SUMMARIZING THE HYPOTHESIS FAVORED BY THE INTERPRETATION OF THE VARIOUS FEATURES IN THE LAKE CALVIN REGION.

Feature	Hypothesis Favored	
	Lacustrine	Fluvial
Theoretical considerations	X	
The Mud-Elkhorn creek valley — the Inlet	X+	X—
The temporary Mississippi river channel of Leverett — the Outlet	X	
Laminated silts, clays and sands in the lake basin	X	
Terraces in the lake basin		
Three terraces of different ages		X
High and intermediate terraces same age, low terrace Iowan	X	
Texture and structure of high and intermediate terraces	X	
Rounded bluff lines of the lake basin	X	
Bowlders in the lake basin	X+	X—
Certain gravel deposits in the lake basin	X	
The Illinoian upland within and without the lake basin	X	
A comparison of the width of the valley in and outside of the lake basin	X	
Illinoian gumbotil	X	

The table shows at once that every feature can be explained very readily by the lacustrine hypothesis, whereas but two out of twelve features can be explained as well by the fluvial hypothesis and only one better. In view of the fact that the weight of evidence is in favor of the lake hypothesis and that this hypothesis is in complete harmony with the gumbotil idea the writer is convinced that Lake Calvin was a reality.

ORIGIN OF LAKE CALVIN.

Since the existence of Lake Calvin has now been established its origin might next be outlined briefly. The Illinoian ice sheet in its advance into Iowa occupied and filled the valley of Mississippi river thereby displacing the stream toward the west. Finding an outlet by way of Maquoketa river, the waters flowed westward to a low col in the vicinity of Preston in Jackson county. From here the combined waters of the two streams flowed southward as far as Wapsipinicon river and thence westward to the mouth of Mud creek from whence a southerly course was pursued over the Mud-Elkhorn divide to Cedar river at Moscow. As the valley of Iowa-Cedar river also was blocked by the same ice sheet on one side and by high Kansan bluffs on the other, the waters of Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa rivers and those flowing from the ice edge rose until the entire lake basin was covered by a wide expanse of water, to which Udden has applied the term 'Lake Calvin.' The lake rose until the level of the now abandoned valley south and southwest of Columbus Junction was reached and afforded an outlet.

CHAPTER VII.

THE DRAINAGE AND HISTORY OF EXTINCT LAKE CALVIN.

Earlier Views Regarding the Duration of Lake Calvin.

Although Udden does not discuss the drainage of Lake Calvin, he undoubtedly was of the opinion that the lake was drained for only a short time by way of the abandoned channel. This is shown by the following sentence quoted from his report. "For most of the time of its subsequent existence it (the lake) must have been a wide expansion of the Cedar river, somewhat like Lake Pepin in the Mississippi of today, with its water level but slightly higher than the present surface of the West Liberty plain."[199] The southern end of the West Liberty plain of Udden or the intermediate terrace of this report has an elevation about 610 feet above sea level or approximately 120 feet below the floor of the now abandoned channel. Our present knowledge of the Pleistocene, especially that concerning the origin of the gumbotils, will not warrant a view such as is suggested by the quoted sentence. Leverett also favors the view that "The abandonment of the lower end of the channel from Columbus Junction southward probably occurred as soon as the ice sheet had withdrawn sufficiently to uncover the present line of the stream, for the altitude along the present Mississippi bluffs is a few feet lower than the bed of the abandoned channel. This lower altitude along the Mississippi is due to the incomplete filling of the preglacial channel by drift."[200] However, Leverett at the time of writing did not see the significance of the gumbotil, although he had seen the gumbotil and had described it. Furthermore, the fact that the Mississippi bluffs are a few feet lower than the bed of the abandoned channel does not preclude the drainage of the lake by way of the abandoned channel south of Columbus Junction. The Illinoian-Mississippian sag if it existed was at least twenty

199 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 355, 1899.

200 Leverett, F., The Illinois Glacial Lobe: U. S. Geol. Survey Monograph XXXVIII, pp. 96-97, 1899.

miles distant from Lake Calvin by way of the present Iowa-Cedar river valley. What the elevation of the intervening topography was is not known. The Illinoian upland at Columbus Junction is about 730 feet above sea level; at Morning Sun, but two and three-fourths miles from the south valley wall of Iowa-Cedar river, it is 752 feet and at Newport, only two miles south of the river bluffs, it is at least 720 feet above sea level. The Mississippi bluffs north of Wapello are at many places over 700 feet above sea level. Leverett also does not appear to have had much faith in the existence of Lake Calvin for he barely mentions the lake in his classic monograph on the Illinois Glacial Lobe.[201] Then too, the absence of notable sand and gravel deposits in the channel should have been the natural clew to suggest to him the presence of the lake. As has been shown in the previous chapter, the absence of such deposits in the channel is in perfect harmony with the lake hypothesis. The lake acted as a filtering plant and so the outflowing stream was free from sediment, hence there should be no deposition. Furthermore, as a stream without a load has minimum erosive power, such material would not be collected, especially if the ground were frozen as suggested by Chamberlin.[202] Thus it is easier to explain the absence of notable deposits of sand and gravel in the channel on the basis of a lake than on that of a frozen stream bed.

The Duration of Lake Calvin.

The writer agrees with the conclusion of Udden[203] that Lake Calvin persisted almost to the time of the Iowan ice incursion, although the means by which he arrived at that view are no longer tenable. It is obvious, if the present view concerning the origin of the gumbotil is correct, that Lake Calvin could not have been drained by way of the Iowa-Cedar river valley shortly after the ice had retreated, since outcrops of Illinoian gumbotil appear on both valley walls of the Iowa-Cedar and the Mississippi river valleys. Hence, to say the least, drain-

201 Idem, p. 96.
202 Idem, p. 93.
203 Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 355, 1899.

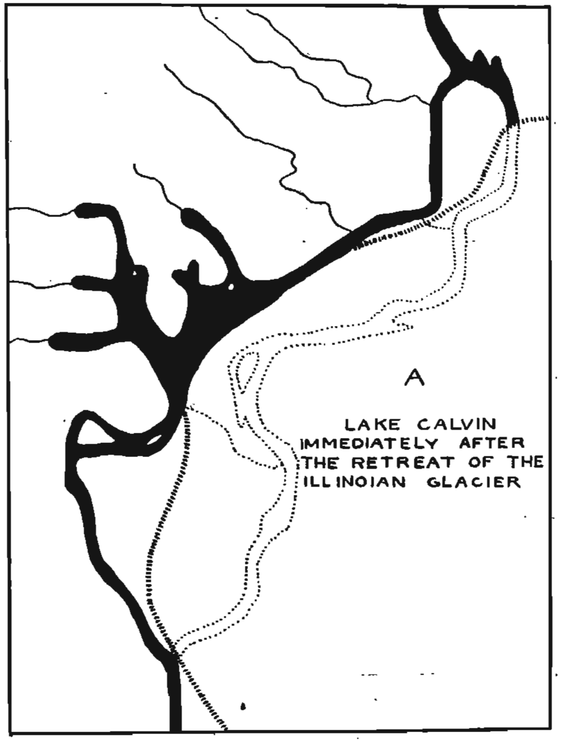
age of the lake by this route is post-Illinoian-gumbotil in age. A long-lived Lake Calvin is in accord with the theory of the formation of the Illinoian gumbotil as the levels of the lake and of the gumbotil as they are shown at Columbus Junction were not separated by more than ten to twenty feet, a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

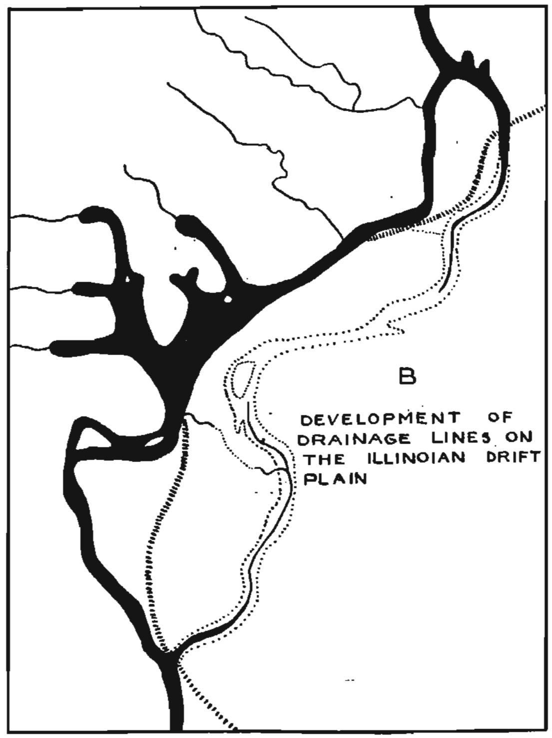
Thus on the basis of the Illinoian gumbotil, the straight line of contact between the high and the low terraces along Iowa river and the great amount of sediment in the lake basin, the writer is convinced that Lake Calvin was not short-lived but existed almost to the time of the Iowan ice invasion.

The Draining of Lake Calvin.

No hypothesis regarding the draining of Lake Calvin has ever been advanced. It is obvious that the main factors in the draining of the ancient lake were the development of streams on the recently formed Illinoian gumbotil plain and stream piracy. Just where and how the piracy took place must remain hypothetical as field evidence is lacking. To begin with, after the Illinoian ice sheet had withdrawn from the region, a long time elapsed before erosion became active. During this period of quiescence, the drift was subjected to the effects of atmospheric weathering and a gumbotil at least five feet thick was formed. That the formation of gumbotil is an exceedingly slow process has been demonstrated by Kay.[204] Then erosion became active due either to diastrophic movements or to the fact that the region lies in close proximity to the master drainage lines. New streams tributary to Mississippi river north and south of the Illinoian area soon developed and worked their way headward into the Illinoian upland. Finally, some stream was able to work its way backward until Lake Calvin was tapped and drained. A possible method by which Lake Calvin was drained is illustrated in Plates XVII and XVIII. Sketch map A of Plate XVII shows Lake Calvin immediately after the retreat of the Illinoian ice sheet. According to the gumbotil idea, the Illinoian drift plain after the disappearance of the glacier consisted essentially of a flat ground moraine very much like that left by the Wisconsin glacier in northcentral Iowa. A prolonged period of weathering followed during which at least five feet of gumbotil was formed. Young streams soon developed on the Illinoian drift plain. It is fairly safe to assume that a stream developed at each end of the buried Mississippi channel as well as at the western edge of the Iowa-Cedar river valley at Columbus Junction, as sags might be expected to exist over buried channels. Sketch B of Plate XVII shows the development of the newly formed drainage lines on the Illinoian drift plain. In the life history of rivers, some streams due to various causes gain advantages over others and finally absorb

204 Kay, G. F., Jour. Geology, Vol. XXVIII, pp. 89-125, 1920.

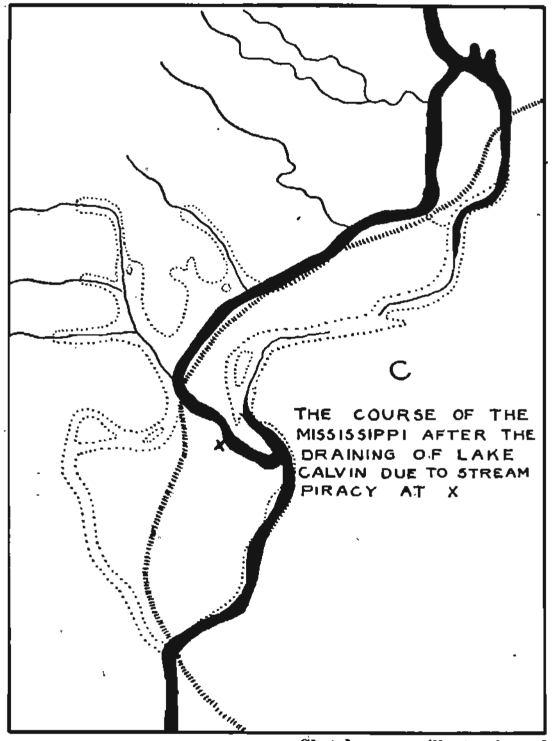


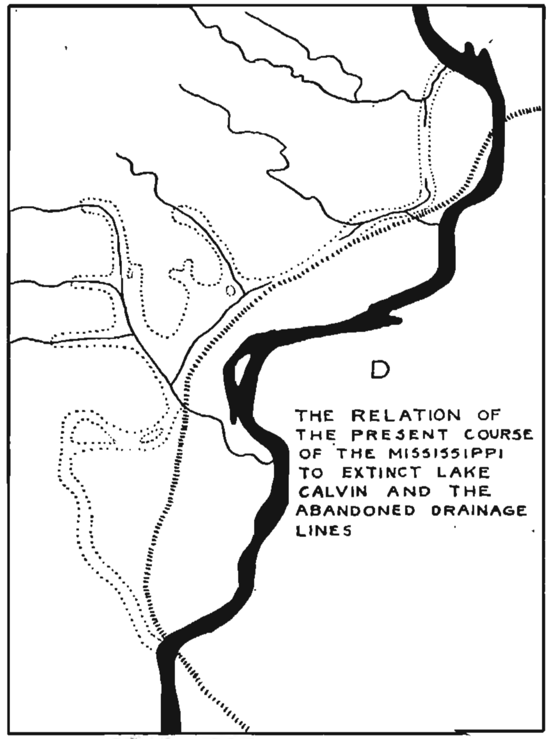


Sketch maps illustrating the draining of Lake Calvin.

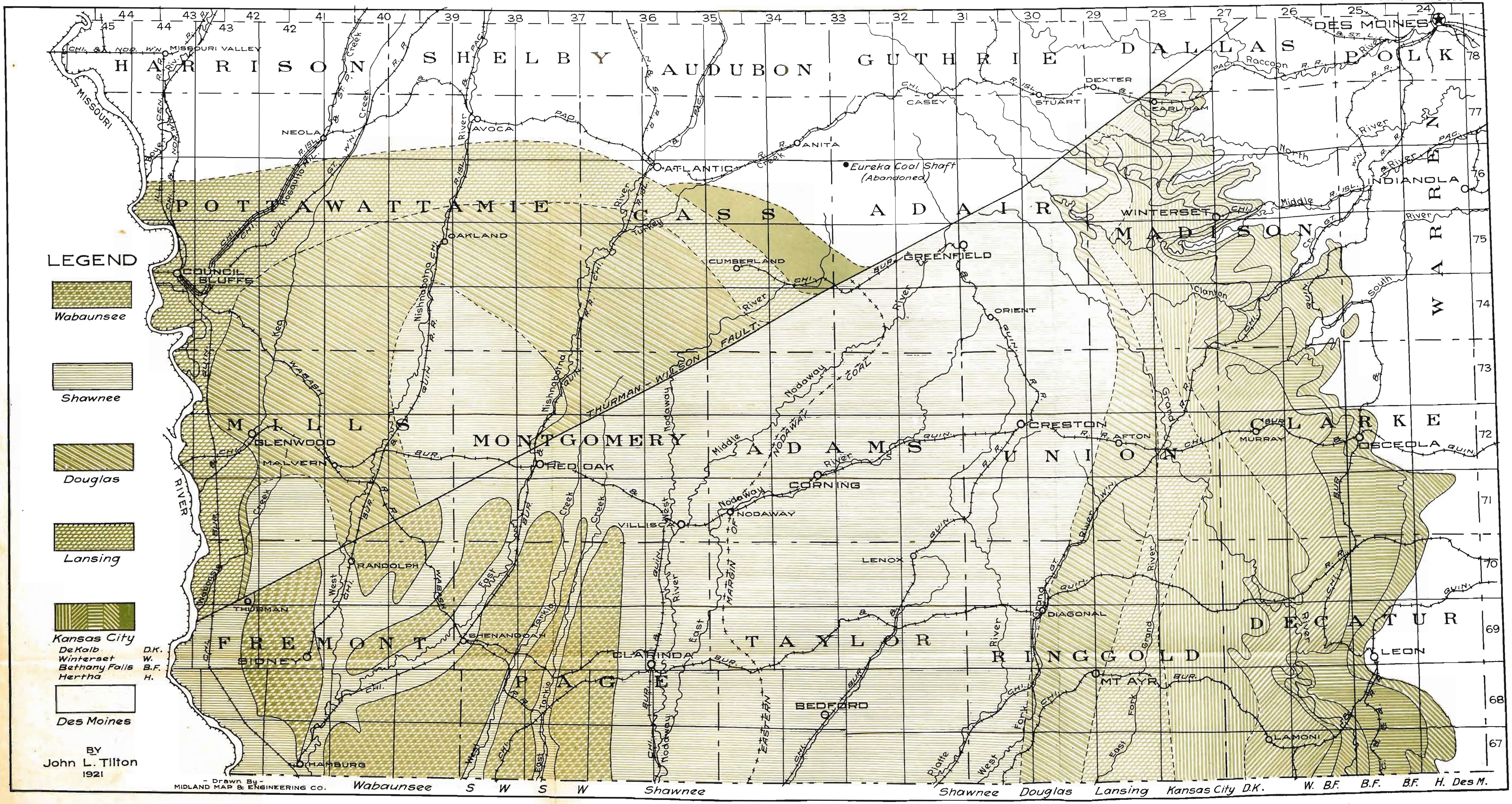
them, thus gaining larger volume and hence more erosive power. For convenience, it may be supposed that the southern tributary of the Mississippi, sketch map C, Plate XVIII, had the advantage over the other youthful streams. Working backward by head erosion, the stream after a time extended its valley as far north as the present mouth of Iowa-Cedar river, where it sent out a branch westward over the course of the buried Iowa-Cedar valley. This tributary, which because of its relation to the master stream had the advantage over the other small streams which occupied the same valley but drained into the lake, soon shifted its divide westward and captured the west flowing stream, thus draining Lake Calvin and directing the course of the Mississippi through its channel. (See sketch map C of Plate XVIII.) Finally, after continued head erosion by the north and south flowing streams in the partly filled Mississippi valley, the north-flowing stream was captured by the south-flowing river and the entire drainage was directed southward as is shown on sketch map D, Plate XVIII.

It is possible that Lake Calvin never was drained by way of the Iowa-Cedar river valley. Stream piracy may have taken place between the north and south flowing streams developed over the buried Mississippi valley rather than in the Iowa-Cedar valley. In that case, the drainage of the lake would have been diverted northward instead of southward. (See sketch maps E and F, Plate XIX.) To have established the drainage as it is now, sketch map D, Plate XVIII, at least one other case of piracy would have been necessary either in the Iowa-Cedar river valley or in the lake basin itself. To the writer, the first view regarding the drainage of Lake Calvin is just as logical as the latter. It may be asked: Why should the tributary developed in the Iowa-Cedar river valley at the mouth of the present Iowa-Cedar river have had the advantage over the main stream? On the assumption that the north and south flowing tributaries of the Mississippi extended their valleys headward at the same rate, the head of the northflowing river would have been a few miles below Davenport at the time that the south flowing stream had extended its valley as far north as the mouth of the present Iowa-Cedar river. If they continued





Sketch maps illustrating the draining of Lake Calvin.



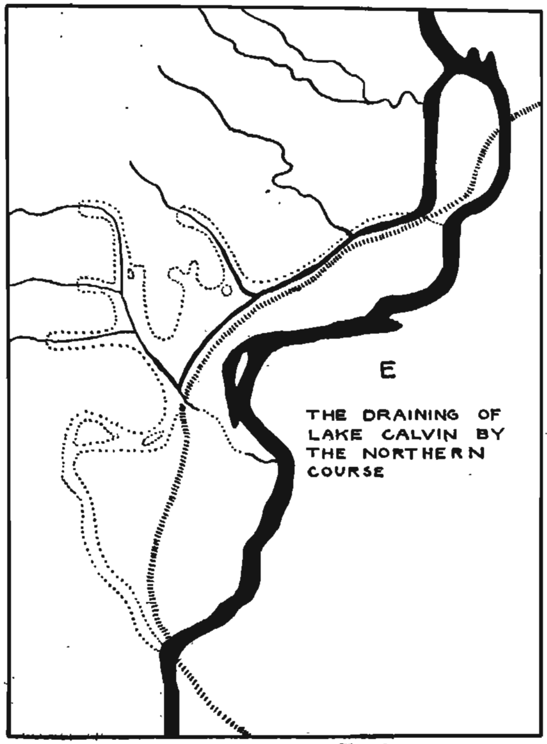
DISTRIBUTION OF THE STAGES OF THE MISSOURI SERIES IN SOUTHWESTERN IOWA.

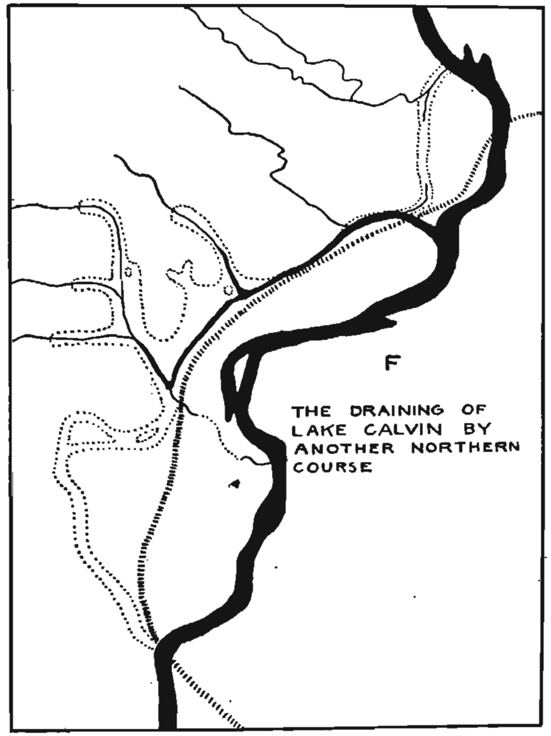
at equal rates the two streams should have met near Muscatine. The distance between the lake basin and the present Mississippi river is equivalent to the distance between the mouth of Iowa-Cedar river and Muscatine. The question arises: "Is it possible that the two tributaries developed over the buried Iowa-Cedar river valley united before the two main streams were able to do so? It seems plausible, especially when it is remembered that in the case of the Iowa-Cedar valley two streams were involved in the same distance that one of the main streams had to work headward before stream piracy could have taken place. Furthermore, the east flowing tributary may have developed as rapidly as the south flowing stream since the former must have been accordant with the latter. Then too, it must be remembered that the two main tributaries did not extend their valleys headward at the same rate for in that case a permanent divide instead of stream capture would have resulted. Also, the south flowing stream had the advantage over the one flowing to the north as the Mississippi is now pursuing a course to the south. Moreover, the greater portion of the valley through which the north tributary flowed is cut into solid rock whereas the valley south of Muscatine is in drift. To the writer, the drainage of Lake Calvin by way of the Iowa-Cedar river valley is more probable than by the more northerly course.

The History of Lake Calvin, a Resume.

After the retreat of the last seas, probably the Cretaceous, the Lake Calvin region underwent a prolonged period of erosion. It is not certain whether the Nebraskan ice sheet advanced over a peneplain as suggested by Trowbridge[205] or whether the region presented a maturely dissected topography similar to that of the famous Driftless Area of southwestern Wisconsin and the adjoining states of Iowa, Illinois and Minnesota. Nevertheless, it is certain that at least before the advent of the Kansan ice, stream valleys two hundred to three hundred feet deep traversed the region in various directions, forming a network of drainage systems comparing very favorably with those of the present time. Of these, at least two occupied the

205 Personal communication.





Sketch maps illustrating the draining of Lake Calvin.

site of the lake basin, one in the region of the present Cedar river, the other in the Iowa river sector of the lake basin. The Nebraskan glacier undoubtedly changed the aspect of the topography, whether it was a peneplain or a highly dissected region, by destroying all valleys which may have existed and leaving on its retreat a glacial topography of low relief. The drift was subjected to weathering and erosion during the ensuing long Aftonian interglacial period so that portions were changed into gumbotil, and the region was deeply dissected[206] before the oncoming of the second glacier, the Kansan. Again the old topography was obliterated and a newly formed ground moraine was left in its place. After the retreat of the ice, more gumbotil was formed and the Iowa and Cedar river valleys were called into existence.

Unlike the other two ice sheets, which entered the lake region from the north, the third or Illinoian ice sheet found its way into the lake region by advancing from the east. The advancing glacier, in crossing into Iowa, blocked the valley of Mississippi river and filled it with ice. This caused the waters of the great river to be dammed back and necessitated the finding of a new course to the west. The stream found an opening by way of the Maquoketa river valley and flowed first westward then southward through the Goose Lake channel to the valley of Wapsipinicon river and finally over the low divide between Mud and Elkhorn creeks to the valley of the Cedar at Moscow. Thence continuing southward to the junction of Iowa and Cedar rivers at Columbus Junction, the combined waters of Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa rivers found their pathway obstructed on the one side by the great ice wall of the Illinoian ice sheet and on the other by the Kansan bluffs which stand 120 to 140 feet high. As the waters could find no outlet, they rose until the entire area of the lake basin was covered by a vast and deep expanse of water to which Udden gave the name 'Lake Calvin.' During the long existence of the lake, the surplus water found its way to the unfilled valley of the Mississippi by a devious course

206 Professor Trowbridge believes that during Aftonian times most of the rough subglacial topography was carved out.

through the now abandoned channel discovered by Leverett and traced by him across several counties to the present valley of the Mississippi below Fort Madison. In the meantime, at least five feet of gumbotil were formed and new streams were developed on the Illinoian drift plain. Finally, shortly before the time of the next or Iowan ice incursion, Lake Calvin was tapped and drained, due to stream piracy. The high and intermediate terraces were soon formed but because of the overloading of the streams by the vast amount of sediment derived from the melting glacier to the north, the terrace formation was halted and a new flood plain was developed. Since the retreat of the glacier, however, Iowa river has been cutting down its new flood plain, producing thereby the low terrace, the destruction of which is still continuing. Thus ends the history of the Lake Calvin basin to the present time.

APPENDIX A

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THE MISSOURI SERIES OF THE PENNSYLVANIAN SYSTEM IN SOUTHWESTERN IOWA

JOHN L. TILTON

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THE MISSOURI SERIES OF THE PENNSYLVANIAN SYSTEM IN SOUTHWESTERN IOWA

Introduction.

In presenting this paper the writer is impressed with the amount of detail that can now be used only in a general way. As the work progressed numerous problems have developed that he is reluctant to defer. He believes, however, that the general presentation here offered is sufficiently exact to be of immediate value in interpreting the Pennsylvanian of southwestern Iowa and in suggesting local problems that may be worked out to further increase the knowledge of the region.

From the date of the earliest geological map of Iowa to the present the Pennsylvanian of southwestern Iowa has been mapped as including what are now called Des Moines and Missouri strata, with no attempt to represent the distribution of the various subdivisions, except as St. John subdivided the Des Moines series. The limestone beds near Winterset and those of southeastern Nebraska attracted the attention of early geologists. The work of White, and later of Bain, Tilton and Leonard, in Madison, Guthrie, Dallas and Decatur counties, brought forth descriptions of strata along the eastern margin of the Missouri series which Bain correlated with the Kansas City stage along Missouri river. Broadhead had made a complete section along Missouri river in Missouri, and this section was reviewed later by Hinds and Greene. The limestone of southeastern Nebraska had been visited by noted geologists, and was then carefully studied by Meek, and later a section was made in detail by Condra and Bengtson. These various reports connected the limestone of beds near Winterset with those in extreme southwestern Iowa by means of outcrops along Missouri river, but the great stretch of Pennsylvanian strata between still remained imperfectly known geologically. So deeply are the strata generally concealed beneath a mantle of thick glacial drift, and so similar are the beds of limestone and shale that such an observer as C. A. White[1] was deceived into thinking that the beds of limestone near Lewis in Cass county were the same as those found at Winterset. To disclose relations in this large area E. H. Lonsdale was assigned Montgomery county (Vol. IV, Iowa Geol. Survey), while H. F. Bain studied Guthrie, Madison and Decatur counties and J. L. Tilton studied Madison county (Vols. VII and VIII, Iowa Geol. Survey). Then S. Calvin studied Page county, where George L. Smith had accumulated much local information, and J. A. Udden studied Pottawattamie county (Vol. XI, Iowa Geol. Survey). Udden then undertook the study of Mills and Fremont counties (Vol. XIII, Iowa Geol. Survey), and Calvin studied Ringgold and Taylor counties, but left the writing of the reports incomplete, to be finished by M. F. Arey (Vol. XXVII, Iowa Geol. Survey). To further aid in a general knowledge of the region the Survey published George L. Smith's paper on "The Carboniferous Section of Southwestern Iowa" (Vol. XIX, Iowa Geol. Survey). Later the study of Clarke and of Cass counties and a review of J. E. Gow's report of Adair county were assigned J. L. Tilton (Vol. XXVII, Iowa Geol. Survey). G. F. Kay studied Union county and James H. Lees Adams county, the reports on which have not as yet been published.

It was as the study of Cass county progressed that the key to one of the main difficulties of the region was discovered. Not only was the region as a whole deeply covered with drift and with Dakota sandstone, leaving only occasional outcrops visible here and there, but a fault, the Thurman-Wilson fault,[1a] already noted near Missouri river, was discovered to cut clear

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1C. A. White, Report on the Geological Survey of the State of Iowa; Vol. II, p. 6, 1870.

1aThis displacement seems to have been first noticed by Professor Todd who described it in a paper entitled Folding of Carboniferous Strata in Southwestern Iowa, Iowa Acad. Science, Vol. I, pt. 1, p. 58, and later discussed it further in Some Variant Conclusions in Iowa Geology, Iowa Acad. Science, Vol. XIII, pp. 183, 184. Todd, however, did not recognize this as a true fault. He stated that "The fold is quite sharp at Jones' Point (on the Nebraska side) and may become a fault on the Iowa side." It remained for George L. Smith to determine the presence of the fault and to locate and describe it accurately. This he did in his paper on The Carboniferous Section of Southwestern Iowa, Iowa Geol. Survey, Vol. XIX. pp. 612, 647-649, 1908. Several years later Keyes mentioned a fault, called by him the Red Oak fault, which evidently is identical with the Thurman-Wilson fault of Smith, although the localities he mentions are different from those named by Smith. See Iowa Acad. Science, Vol. XXIII, p. 106, 1916. Keyes has also mentioned the fault again in the June, 1922, number of the Pan-American Geologist.

Another paper which discusses this fault is by Tilton and is entitled: The Thurman-Wilson Fault Through Southwestern Iowa and Its Bearing. Jour. Geol., Vol. XXVII, pp. 383-390, 1919. The fault is discussed also by Tilton in The Geology of Cass County, and The Geology of Adair County, Iowa Geol. Survey, Vol. XXVII, pp. 209-216, 301-304. See also further discussion of this fault on page 251 of this volume.

across the area, beneath the Dakota sandstone and the drift. It was not until the work on the present paper was in progress that the explanation of peculiar conditions along the entire northern border of the area was discovered: not only were strata removed by erosion from the north side of the fault, but the Kansas City stage was largely absent if it was present at all, the limestone at Stuart had previously been misinterpreted, and an overlap had brought the strata of the Lansing stage next to areas of the Des Moines series.

In preparing this paper the writer has drawn freely from the carefully prepared published descriptions of strata and lists of fossils, believing them to be far more complete and accurate than any which he could prepare in two field seasons' study of so extensive an area. He has, however, visited the most important outcrops previously described, and many that are not important, and compared the printed descriptions of outcrops with the outcrops as they now exist. Where no credit is mentioned the writer makes use of his own descriptions. He wishes especially to acknowledge the assistance of Mr. Ivan Willis and Mr. Byron C. Hopper, two students whose activities contributed materially to the accumulation of data in the field. He also wishes to express appreciation of the careful oversight of James H. Lees, Ph.D., the Assistant State Geologist, while the report is in press.

The area covered in this report lies south of a line extending straight west from Des Moines to Missouri river, and west of a line from Des Moines straight south to the Iowa-Missouri state line. The area is thus approximately 8,820 square miles. The work is confined to the Missouri series though the subdivisions of the Des Moines series that lie next to the Missouri series are mentioned.

After presenting descriptions of the various members of the divisions of the Missouri series and lists of the fossils it is thought best to construct cross sections through the region as follows:

1st, Along Missouri river from Hamburg to Crescent, near Council Bluffs.

2d, Along Nishnabotna river, and across to Middle river.

3d, From Nebraska City, Nebraska, to Decatur City and Leon, Iowa.

4th, Along Grand river with extension to Middle river.

5th, Along Middle river from Winterset to Stuart, connecting with the section from Leon and the one along Nishnabotna river.

The structure of the region as a whole is then described, and the areal distribution of the divisions is mapped.

Nomenclature.

The nomenclature discussed by Hinds and Greene in their report on the "Stratigraphy of the Pennsylvanian Series in Missouri," Missouri Bur. Mines, Bull. XIII, pages 27 and 115, which was previously adopted, with the exception of one term, for the reports on Clarke and Cass counties, is adopted for this report, with the exception of the same term, and the addition of subdivisions to the Wabaunsee stage. The Nebraska terms are also used wherever it is found desirable to introduce them.

The exception referred to is the term Drum limestone, instead of which the term De Kalb limestone will be used in this report. The term De Kalb was used by Bain[2] in his report on Decatur county in 1897 to replace the descriptive term Fusulina limestone. This was six years prior to the use of the term Drum.[3] Had Hinds and Greene been aware of the identity of the Drum and the De Kalb limestones undoubtedly they would have adopted the term De Kalb, for the De Kalb "agrees faunally and lithologically with that member (Drum) in northern Missouri," and is the next limestone immediately above the Cherryvale shale.

The Westerville[4] limestone is here treated as the equivalent of the De Kalb limestone, for near Westerville it occupies precisely the position described for the De Kalb limestone, the beds beneath along Sandy creek having the distinctive characteristics of the Cherryvale shale. Furthermore, in northern Decatur county a set of limestone beds which normally is forty-eight[5] feet thick and lies above the Bethany Falls (Earlham)

2H. F. Bain, Geology of Decatur County; Iowa Geol. Surv., Vol. VIII. p. 278.

3G. I. Adams, Stratigraphy and Paleontology of the Upper Carboniferous Rocks of Eastern Kansas; U. S. Geol. Survey, Bull. 211, p. 37, 1903.

4Hinds and Greene think that their "Cement City" bed "is possibly the same as the Westerville limestone of Iowa, but the correlation cannot be definitely made."

5H. F. Bain, Geology of Decatur County; Iowa Geol. Survey, Vol. VIII, p. 277.

limestone does not exist. All the limestone that is now exposed at De Kalb has the characteristics of the Bethany Falls (Earlham) limestone, one point which Bain himself noted when remarking upon the absence of a Fusulina[6] bed, so evident elsewhere in the limestone above the Cherryvale shale. The definition, however, does not apply to beds elsewhere, as near Winterset; but the term Westerville, supposed to apply to a limestone above the De Kalb, is dropped, except as it may be used in parentheses to call attention to a particular bed near Westerville.

The Wabaunsee[7] stage is here divided into four members: Preston limestone, a shale, Tarkio limestone, and McKissick Grove shale.

The Preston[8] limestone is the lowest limestone at Calvin's type section, number 1 in the description of rocks in sections 22 and 27 of Tarkio township, Page county.[9] The base of the Preston limestone forms the base of the Wabaunsee stage.

The term Tarkio limestone is restricted to the uppermost beds of limestone, two or three in number, as numbers 5 to 8 in the type section referred to. No name is suggested for the shale and soft limestone between the two members: numbers 2 to 4 of the type section; the shale may be designated as the shale between the Preston and Tarkio limestone.

The term McKissick Grove was originally used to designate a location, as the "limestones and shales at McKissick's grove."[10] Condra and Bengtson applied the name as a formational name[11] to those shales that are above the Tarkio limestone. Smith[12] the following year also used the name as a formational name. The term is here applied to all of the strata that are found in Iowa above the Tarkio limestone. It begins with number 8 (the shale under the Nyman coal) and includes

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6Idem, p. 278.

7C. S. Prosser, The Classification of the Upper Paleozoic Rocks of Central Kansas: Journal of Geology, Vol. III, p. 682, 1895.

8Condra and Bengtson, The Pennsylvanian Formations of Southeastern Nebraska: Nebraska Acad. Sci., Vol. 9, No. 2, p. 28, Feb., 1915.

9Iowa Geol. Survey, Vol. XI, p. 430.

10G. L. Smith, The Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 639.

11The Pennsylvanian Formations of Southeastern Nebraska, p. 28, 1915.

12G. L. Smith, Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, p. 86, 1916.

all the numbers above in Smith's description of the limestones and shales at McKissick grove.[13]

The accompanying table expresses a correlation of terms that may be found in use. The second table is a synoptical table of formations as the names are used in this report.

13G. L. Smith, The Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 639.

CORRELATION OF TERMS.

Feet	Hinds and Greene, Strat. Penn. Series in Missouri	Keyes, Vol. 7, Proc. Iowa Acad. Sci.		No.	Condra and Bengtson, Nebraska Section	G. L. Smith, Vol. XIX, Iowa Geological Survey	Feet		Other Names
		Cottonwood ls.							
100+	Wabaunsee	Atchison sh.				M'Kissicks Grove sh.	75		Admire sh.
	Tarkio ls.			18	Tarkio	Tarkio ls.	25		Barclay, Emporia ls.
350-475	Shawnee			17	Preston	City Bluffs Beds	210		Willard sh.
	Scranton sh.			16	Fargo				
	Howard ls.	Osage sh.		15	Burlingame			Atchison sh.	
	Severy sh.			14	Rulo				
				13	Ashland				
				12	Southbend	Bradyville ls.	45		
				11	Louisville				
		Topeka ls.		10	Union				
	Topeka ls.	Calhoun sh.		9	Meadow				Hartford ls.
	Calhoun sh.	Forbes ls.	Platte sh.						
	Deer Creek ls.	Tecumseh sh.		8.	Forbes	Forbes sh.	18		Stennett, Nodaway
	Tecumseh sh.	Lecompton ls.							
	Lecompton ls.			7	Cedar Creek				
				6	Cullom				
	Kanwaka sh.	Lecompton sh.				Platte sh.	86		
200-300	Douglas								
	Oread ls.	Plattsmouth ls.		5	Plattsmouth	Plattsmouth ls.	40		
				4	Weeping Water				
	Lawrence sh.	Andrew sh.		3	Oreopolis	Andrew sh.	172		Strawn, Kickapoo, Ottawa
	Iatan ls.	Iatan ls.	Lawrence sh.	2	Sturm				
	Weston sh.	Weston sh.		1	Nehawka	Iatan ls.	16		
100-140	Lansing					Weston sh.	76		Piqua, Garnett, Burlington, Cave Rock
	Stanton ls.	Stanton ls.				Plattsburg ls.	19		
	Villas sh.								
	Plattsburg ls.	Parkville sh.							
	Lane sh.								Leroy sh.
200-225	Kansas City					Parkville sh. (including Iola)	22		Carlyle ls.
	Iola ls.	Iola ls.							
	Chanute sh.								
	Drum ls.	Thayer sh.							Westerville ls., Cement City ls., DeKalb, Fusulina, Dennis
	Cherryvale sh.								
	Winterset ls.								
	Galesburg sh.								
	Bethany Falls ls.	Bethany ls.				Bethany ls.	165		Earlham, Mound Valley
	Ladore sh.								
	Hertha ls.								Fragmental ls.
950-1140							969		

SYNOPTICAL TABLE OF FORMATIONS.

Group	System	Series	Stage	Substage	Character of Rocks	Nebraska Terms: for Comparison
Paleozoic	Pennsylvanian	Missouri	Wabaunsee	McKissick Grove	Shale	
				Tarkio	Limestone	Tarkio
					Shale	
				Preston	Limestone	Preston
			Shawnee	Scranton	Shale	Fargo Burlingame Rulo
				Howard	Limestone	Ashland Southbend
				Severy	Shale; Nodaway coal	Louisville Union
				Topeka	Limestone	Meadow
				Calhoun	Shale	
				Deer Creek	Limestone	Forbes
				Tecumseh	Shale	
				Lecompton	Limestone	Cedar Creek Cullom
				Kanwaka	Shale	
			Douglas	Oread	Limestone	Plattsmouth
						Weeping Water
				Lawrence	Shale	Oreopolis
				Iatan	Limestone	Sturm
				Weston	Shale	Nehawka
			Lansing	Stanton	Limestone	
				Vilas	Shale	
				Plattsburg	Limestone	
				Lane	Shale	
			Kansas City	Iola	Limestone	
				Chanute	Shale	
				DeKalb	Limestone	
				Cherryvale	Shale	
				Winterset	Limestone	
				Galesburg	Shale	
				Bethany Falls	Limestone	
				Ladore	Shale	
				Hertha	Limestone	

Chief Physical Characters.

The Kansas City Stage.—The thicknesses of the various members are as follows, where these are not diminished by erosion:

	FEET	INCHES
Iola limestone	3	
Chanute shale	17	3
De Kalb limestone	13	10
Cherryvale shale	16	
Winterset limestone	13	10
Galesburg shale	10	
Bethany Falls limestone	20	
Ladore shale	21	
Hertha limestone	16	6
	131	5

In the description of local sections used in plotting the cross sections the section at Winterset may be considered as a standard.

The Hertha limestone is in two portions with shale between. It contains an abundance of *Composita subtilita* and but few of the other usual Pennsylvanian fossils. While it is so fragmental as to have merited that name as a descriptive term, it is not the only fragmental limestone in the stage. The Bethany Falls and the Winterset limestone beds are each fragmental at the top, but are not fragmental throughout as is the Hertha.

The Ladore shale has a stratum eight inches thick of dark limestone four feet below its upper limit.

The Bethany Falls limestone is now the chief escarpment maker along ravines cut in the eastern front of the strata of the Missouri series. The thickest beds are near the base.

The Galesburg shale is gray in its upper and lower portions and black through the center.

The Winterset limestone is generally in two beds with the thicker bed at the top.

The Cherryvale shale has near its center a blue limestone separated into three parts by bands of shale the lower of which is very thin. This horizon is the most distinctly marked by fossils of any in the Kansas City stage. This limestone is a *Myalina* horizon, with *Orthotetes crassus* and *Chonetes verneuilianus* in abundance. In the shale beneath the blue limestone the *Chonetes* are so numerous as to constitute thin beds of limestone.

The De Kalb limestone contains numerous small *Fusulina* in a matrix of fine calcareous material. In the western part of Madison county it is conspicuous in the low escarpment that extends along the east side of Middle river south of Webster where it shows its greatest thickness. The top, where the full thickness is present, is made up chiefly of calcareous pebbles, and is somewhat arenaceous. The lower five feet is rich in large *Fusulinas*.

The Chanute shale is thickest along Brushy creek near the west line of Madison county. The lower portion consists of fossiliferous limestone and calcareous shale, and the upper half of drab, red and green shale.

The Iola limestone member includes the next two limestones above the colored shale, with the sixteen-inch bed of shale between them. The lower bed is somewhat fragmental; the upper bed is fossiliferous.

The Douglas-Lansing Stages.—From the top of the Iola limestone, or, better still, from the top of the De Kalb limestone, to the base of the Oread limestone (a definite horizon) there is a succession of limestones and shales that are difficult of assignment to the divisions as recognized in Missouri and Nebraska. The beds outcrop in ravines along the southwest side of Middle river from two miles south of Webster to the central part of Harrison township, Adair county. The strata may be met within a distance of two miles, and the vertical difference in elevation is only forty-nine feet, which is distributed as follows:

	FEET	INCHES
Douglas stage:		
Lawrence shale	6	8
Iatan limestone	4	6
Weston shale	4	
Lansing stage:		
Stanton limestone	3	8
Vilas shale	16	
Plattsburg limestone	5	6
Lane shale	9	
	49	4

In Missouri these beds, up to the thickest beds of the Oread limestone (Broadhead's number 150), measure about 260 feet in thickness for the Douglas stage and about 127 feet for the Lansing stage. In Missouri the Plattsburg limestone member is 18 feet thick; in central Iowa it is 5 feet, 6 inches thick. In Missouri the Stanton limestone member contains 23 feet of limestone. In the Iowa region the Stanton limestone is but

3 feet, 8 inches thick.[14] The shaly members also are much thinner in Iowa than in Missouri.

The Nebraska section recognizes four groups of limestone beneath the Oread (Plattsmouth) limestone, referring them to the Lawrence shale:

	FEET
Shale	18-20
Weeping Water limestone	6
Shale	30
Oreopolis limestone	6-9
Shale	6
Sturm limestone, about	6
Shale	4
Nehawka limestone	10 or more
	88+

It is evident that the topmost shale in this section should be referred to the Lawrence shale, as the term is used in Missouri, and that the groupings of the limestone members would make the Nehawka correspond to the Iola limestone. It is clear that both limestone and shaly members in this general horizon are much thinner in eastern Adair than they are in southeastern Nebraska.

The Shawnee Stage.—The various thicknesses of the members of the Shawnee stage are as follows:

	FEET	INCHES
Scranton shale	194	6
Howard limestone	4	
Severy shale	25	3
Topeka limestone	6	
Calhoun shale	11	4
Deer Creek limestone	8	
Tecumseh shale	65	
Lecompton limestone	7	
Kanwaka shale	16	
	337	1

The thicknesses given for the very thick shales in the above list are obtained from the record of the Clarinda diamond drill hole, and not from measurement of outcrops, for they do not outcrop in such a way that measurement of the thickness is possible.

The portion of the Oread limestone that is characterized by "millions of *Fusulina*" closely packed together, as Meek[15] de-

[14] The comparison is based on pages 113 and 114 of Hinds and Greene's Stratigraphy of the Pennsylvanian Series in Missouri.

[15] F. B. Meek, Report on the Paleontology of Eastern Nebraska, pp. 92-93.

scribed the beds near Plattsmouth fifty years ago, has the same characteristics where it outcrops at Riverview Park north of Red Oak and in Harrison township in eastern Adair. This makes a very good horizon from which to work upward in the vicinity of Stennett in an endeavor to correlate those beds with the corresponding beds in eastern Nebraska. The sequence can be traced without difficulty along the road and then up the ravine north of Stennett, from the Oread to and including the Severy (Louisville limestone), except that the Lecompton (Cullom) limestone is beneath the river deposits. The thicknesses of these groups of strata are as follows, each including the shale above it:

Near Stennett FEET	INCHES			Nebraska FEET
2		Severy	Louisville	16½-22
8	8		Union	25
4	5	Topeka (Calhoun)	Meadow	6
8		Deer Creek	Forbes	31 limestone
?		(Tecumseh)		13-16 shale
			Cedar Creek	7-8 limestone
?		Lecompton		7-8 shale
			Cullom	8 limestone
?		(Kanwaka)		13 shale
6	10	Oread	Plattsmouth	25-30 ?

Here also it is evident that the various members thin out toward the northeast.

The Deer Creek limestone is recognized also farther southeast on the south side of the Thurman-Wilson fault.[15a] The uppermost limestone that is exposed at Hawleyville evidently is the Topeka (Meadow) limestone. The other Nebraska members, Union to Ashland, are portions of what has been called Braddyville limestone in Iowa by Smith, and the Severy shale, Howard limestone, and Scranton shale in Missouri. The Nodaway coal seam forms a marked horizon in the upper part of the Severy shale. A gray shale immediately underlies the coal and the Howard limestone is about four feet above it.

The Cullom and Cedar Creek limestones that are in the valley northwest of Riverview Park, Red Oak, and near Stennett correspond to the Lecompton limestone of Missouri, the shale above these two limestones corresponds to the Tecumseh shale,

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[15a]See note [1a] on page 228.

and that below them and extending down to the Oread limestone, is the Kanwaka shale.

The Scranton shale of the Missouri survey extends from the top of the Howard limestone to the base of the Preston limestone. The Rulo, Burlingame and Fargo limestones of Nebraska may be considered as parts of the Scranton shale. Except the Fargo they have not been recognized as distinct beds in Iowa. The Fargo appears at the base of the McKissick grove section, and at an outcrop a mile southwest of Red Oak.

The Wabaunsee Stage.—The four members of the Wabaunsee stage as here recognized have the following thicknesses in Iowa:

	FEET
McKissick Grove shale	93
Tarkio limestone	4
Shale	12
Preston limestone	2
	111

The Preston limestone member is essentially a single ledge. The Tarkio is a blue hard limestone at the base and a Fusulina limestone at the top. The shale between the Preston and Tarkio limestones is an ordinary gray shale including a thin bed of light colored limestone. The McKissick Grove shale is increasingly arenaceous and micaceous toward the top, and also toward the south into Missouri.

The above terminology avoids the use of the terms Osage shale, Platte shale, Braddyville limestone, City Bluffs shale and Atchison shale, which have been variously used to include several members of the upper part of the Shawnee stage.

THE IOWA SECTION OF THE MISSOURI SERIES.

	FEET	INCHES
Wabaunsee stage (total thickness in Iowa, 108 feet):		
McKissick Grove shale (total thickness, 91 feet)—		
Shale, blue	12	
Shale, gray	8	
Limestone, very dark gray, arenaceous, many spheroidal lumps, in places brecciated	1	
Limestone, blue, very arenaceous: a calcareous sandstone	1	
Shale, arenaceous, micaceous	3	
Sandstone, blue, weathering yellow	6	
Shale, arenaceous, micaceous	2	6
Sandstone, blue, weathering yellow	1	
Shale, gray	9	
Limestone, dark gray, fossiliferous; in two layers	3	
Coal, Nyman	1	

	FEET	INCHES
Shale, yellow and blue	31	
Limestone, gray, fossiliferous		6
Shale, dark gray	3	6
Limestone, very dark gray		6
Shale, blue, weathering to yellow	8	
Tarkio limestone—		
Limestone, weathering brown; in two or three layers	4	
Shale, not named—		
Shale, gray, between Tarkio and Preston limestones	12	
Preston limestone—		
Limestone, dark gray	1	
Shawnee stage (total thickness, 337 feet, 1 inch):		
Scranton shale—		
Shale, variously colored; from estimate by Smith	194	6
Howard limestone—		
[16]Limestone, yellowish	4	
Severy shale—		
[16]Shale; includes Nodaway coal, Louisville limestone (2 feet), Union limestone and shale above it (8 feet, 8 inches)	25	3
Topeka limestone		
Limestone, near Stennett	6	
Calhoun shale		
Shale, near Stennett	11	4
Deer Creek limestone—		
Limestone, near Stennett	8	
Tecumseh shale—		
[16]Shale	65	
Lecompton limestone—		
[16]Limestone	7	
Kanwaka shale—		
[16]Shale	16	
Douglas stage (total thickness, 25 feet, 7 inches):		
Oread limestone (at Riverview Park, Red Oak) (thickness, 10 feet, 5 inches)—		
Limestone, upper part decomposed; fossiliferous; many *Fusulinas*	1	10
Shale		1
Limestone, gray		5
Shale, greenish gray		3
Limestone, with light colored flint	1	6
Shale		1
Limestone, gray		8
(Below this plane the limestone is full of *Fusulina.*)		
Limestone, gray, in three parts	1	9
Shale, brown		1
Limestone, shaly below	1	3
Limestone, in three parts, the second shaly	1	6
Lawrence shale (eastern Adair county)—		
Shale, gray, fossiliferous	6	8
Iatan limestone(thickness, 4 feet, 6 inches)—		
Limestone, dark gray, fossiliferous		7
Shale, calcareous		8
Limestone, gray and dark, weathers brown, fossiliferous	3	3
Weston shale—		
Shale, gray above and below, black in center	4	
Lansing stage (total thickness, 36 feet, 1 inch):		
Stanton limestone (thickness, 3 feet, 8 inches)—		
Limestone, gray, dense, fossiliferous	1	2
Shale, blue	1	
Limestone, dark gray		6

[16]The total thickness is from the record of the Clarinda Diamond Drill hole, Iowa Geol. Survey, Vol. XIX, page 618.

	FEET	INCHES
Vilas shale—		
Shale, gray and green, with iron concretions at top	21	
Plattsburg limestone—		
Limestone, lower portion dense, gray	5	6
Lane shale (thickness, 6 feet, 11 inches)—		
Shale, green, clayey	2	6
Limestone, greenish, lower half shaly	1	4
Shale, greenish	1	6
Limestone, dense		7
Shale, gray, arenaceous, micaceous and calcareous	1	
Kansas City stage (total thickness, 131 feet, 5 inches):		
Iola limestone (thickness, 3 feet)—		
Limestone, very fossiliferous		10
Shale, gray above, dark below	1	4
Limestone, somewhat fragmental		10
Chanute shale (thickness, 17 feet, 3 inches)—		
Shale, drab	4	8
Shale, red	4	3
Shale, green, calcareous	1	
Limestone, bluish, somewhat fragmental above	2	10
Shale, gray, several nodular calcareous layers	4	6
DeKalb limestone (thickness, 13 feet, 10 inches)—		
Limestone, of calcareous pebbles, upper part slightly arenaceous	5	10
Limestone, gray, thin layers above, thick below, fossiliferous	8	
Cherryvale shale—		
Shale, gray above and in lower portion, three layers of blue limestone between; limestone and all below very fossiliferous	16	
Winterset limestone (thickness, 13 feet, 10 inches)—		
Limestone, gray, fragmental in upper portion	5	2
Limestone, gray, very resistant ledge; with chert	2	3
Limestone, gray	1	2
Shale, gray, argillaceous		3
Limestone, gray	1	9
Limestone, gray; partings of shale	3	3
Galesburg shale (thickness, 10 feet)—		
Shale, gray, argillaceous	1	6
Shale, black	1	6
Shale, gray, argillaceous above, calcareous below	7	
Bethany Falls limestone—		
Limestone, gray, in beds from 1 foot to 1 foot, 6 inches thick; top portion fragmental; fossiliferous	20	
Ladore shale (thickness, 21 feet)—		
Shale, gray, argillaceous	2	10
Shale, black (seam of coal elsewhere)	1	2
Limestone, dark blue		8
Shale, calcareous in places	1	10
Limestone, gray	1	5
Shale, gray, argillaceous	4	9
Limestone, gray	1	10
Shale, gray, argillaceous	6	6
Hertha limestone (thickness, 16 feet, 6 inches)—		
Limestone, gray	2	8
Shale, gray, argillaceous	8	10
Limestone, gray, very fragmental	6	
Total thickness of Missouri stage	638	2

Faunal Relations.

The Kansas City Stage.—The first faunal unit includes the whole of the Kansas City stage, though the fauna of the uppermost beds presents a contrast to that found in the lowest beds. It has long been recognized that the Kansas City stage in Iowa does not contain *Chonetes mesolobus* but has instead *Chonetes verneuilianus;* that it does not contain *Marginifera muricata* but does contain *Marginifera longispina,* and that the fauna in general changes from that of a sandy shore and of brackish water sandstone and shale (Des Moines series) to that of limestone and shale of a more open sea. Under such conditions an off-shore fauna migrated back and forth with little significant change. The different limestones must be recognized in the field largely by the sequence in their beds and by their relation to the shales above and below, features which have already been included in the descriptions of the various members of the Missouri series, and will be included also in the descriptions accompanying the transverse sections across the region. The faunal lists follow these comments.

The Hertha limestone has *Composita subtilita* as a specially characteristic form.[17] Near St. Charles there is an isolated ledge of *Chaetetes milleporaceous,* that seems to be held over from the Des Moines series, but it is not found elsewhere.

The Bethany Falls limestone has, along with the usual assemblage of fossils, an occasional *Phillipsia* in the shaly partings, but they are too rare to be of use in distinguishing these beds from other beds near at hand—in which they have not been found.

The Winterset limestone has in the shaly parting between the two main beds of limestone a bed of *Composita subtilita* of especially large forms.

The Cherryvale shale presents the most distinctive faunal horizon to be found in the Kansas City stage. There is nothing like it to be found elsewhere in the Missouri series, the nearest approach being in the Deer Creek. *Chonetes verneuilianus,* abundantly distributed through the shale in the lower half of the member, is so abundant in places as to constitute thin beds of shaly limestone. The three thin beds of blue limestone about midway in the member comprise a *Myalina*

17The long list of fossils that Bain gives from the limestone near Stuart, Iowa, is not of fossils from the Hertha limestone, but from a bed deep down in the Des Moines series (Henrietta): H. F. Bain, Geology of Guthrie County: Iowa Geol. Survey, Vol. VII, pp. 447-448. See John L. Tilton, The Strata near Stuart, Iowa: Bull. Geol. Soc. America, Vol 33, p. 153, 1922.

horizon, containing two species, *swallovi* and *subquadrata*. Along with these are numerous *Orthotetes* (*Derbya*) *crassus* and an occasional *Meekella striatocostata*.

While the lower part of the De Kalb limestone was originally called a Fusulina limestone the fusulinids are not always present in abundance, and are small in size. The occasional echinoid spines, the fusilinids and the Bryozoa relate the upper beds of the De Kalb to the Iola, and the relative abundance of these forms helps distinguish the upper members from the lower members of the stage.

The Lansing Stage and the Douglas Stage.—The faunal unit recognized by Beede and Rogers includes both the Lansing and the Douglas stages. The fauna marks an advancing open sea that reached its culmination when the Oread limestone was laid down. A detailed study of the thin beds below the Oread may lead to further faunal differentiations, as the beds are very fossiliferous but not easily accessible. It is here that *Enteletes hemiplicata* and *Chonetes granulifer* are first found, differentiating the Lansing from the Kansas City stage. Beede mentions the presence of *Rhipidomella pecosi* and *Derbya bennetti*, and calls attention to a form with a more costate habit to which he gives the name *Marginifera wabashensis*. *Meekella striatocostata*, which he did not find below this horizon in the Missouri collections, is occasionally found in the Winterset limestone at Winterset. Beede further recognizes the introduction of the following in the Douglas fauna: *Chonetes geinitzianus*, *Marginifera lassellensis* and *Tegulifera armata*.

In the Oread limestone there is such a remarkable assemblage of large *Fusulina* closely packed together as to distinguish this horizon from all others. This characteristic is a widespread one, as noticeable in eastern Adair county, Cass county and at Riverview Park in Montgomery county as at the mouth of the Platte river in Nebraska, where Meek[18] emphasized the abundance of it.

The Shawnee Stage.—The fauna of the Shawnee stage centers in that of the Deer Creek member, beds of which outcrop north of Stennett and at Hawleyville. Even here distinctions

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18F. B. Meek, Report on the Paleontology of Eastern Nebraska: p. 93, 1872.

find their chief emphasis in the associated character of the strata. The black chert contains white *Fusulina*—excellent microscopic material; and the limestone contains such an abundance of echinoid spines that they become a characteristic form. Greene notes that the limestone over the Nodaway coal seems largely made up of Ostracods. The central part of the Scranton shale, as exposed at "City Bluffs" a few miles south of the state line, is marked by a bed of *Aviculopecten*.

The Wabaunsee Stage.—Here also the important distinctions are physical rather than faunal. The lower portion contains the Preston and Tarkio limestones with the faunas listed below. The upper part of the McKissick Grove shale is increasingly arenaceous and micaceous toward the top, with fauna as given below. While the character of the deposits indicates a return of shallow water conditions that according to reports elsewhere were widespread, the faunal relations do not depart widely from those in the lower part of the stage. The presence of mica, though it is not a fossil, is especially noteworthy.

FAUNAL LISTS

THE WABAUNSEE STAGE.

McKissick Grove shale.[19]

Upper limestone fauna

- Fusulina cylindrica (secalica)
- Lophophyllum profundum
- Ceriocrinus hemisphericus
- Fenestella perelegans
- Fistulipora nodulifera
- Rhombopora lepidodendroides
- Ambocoelia planoconvexa
- Chonetes geinitzianus
- Chonetes granulifer
- Composita subtilita
- Hustedia mormoni
- Marginifera wabashensis
- Productus cora
- Productus semireticulatus
- Pugnax uta
- Spirifer cameratus
- Allorisma terminale
- Aviculopecten occidentalis
- Aviculopecten providencensis
- Edmondia nebrascensis
- Myalina swallovi
- Bucanopsis marcouanus
- Euphemus carbonarius

Cap rock to Nyman coal

- Fusulina cylindrica (secalica)
- Crinoid stems
- Rhombopora lepidodendroides
- Ambocoelia planoconvexa
- Chonetes granulifer
- Enteletes hemiplicata
- Marginifera longispina
- Orthotetes crassus
- Productus costatus
- Productus punctatus
- Productus semireticulatus
- Pugnax uta
- Composita subtilita
- Spirifer cameratus
- Edmondia nebrascensis?
- Macrodon tenuistriatis?
- Myalina subquadrata
- Nucula?
- Schizodus?
- Euomphalus catilloides
- Phanerotrema grayvillensis
- Pleurotomaria perhumerosa?
- Griffithides scitula

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[19]George L. Smith, Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci.: Vol. XXIII, pp. 86-87, 1916. J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 152 (Section XIX, number 16 for Cap Rock of Nyman Coal).

Lower shale fauna
Fusulina cylindrica (secalica)
Lophophyllum profundum
Ceriocrinus hemisphericus
Fistulipora nodulifera
Rhombopora lepidodendroides
Ambocoelia planoconvexa
Chonetes geinitzianus
Chonetes granulifer
Composita subtilita
Dielasma bovidens
Enteletes hemiplicata
Hustedia mormoni
Meekella striatocostata
Orthotetes crassus
Productus cora
Productus costatus
Productus (Pustula) nebrascensis
Productus punctatus
Productus semireticulatus
Pugnax uta
Rhipidomella pecosi
Spirifer cameratus
Aviculopecten occidentalis
Aviculopecten whitei
Edmondia nebrascensis
Entolium aviculatum
Leda bellistriata
Myalina perattenuata
Myalina subquadrata
Myalina swallovi
Parallelodon wheeleri
Aclisina stevensana
Bucanopsis montfortiana
Euomphalus catilloides
Euphemus carbonarius
Phanerotrema grayvillensis

Tarkio limestone.[20]
Fusulina cylindrica
Zeacrinus (numerous segments)
Rhombopora lepidodendroides
Ambocoelia planoconvexa
Chonetes geinitzianus
Chonetes granulifer
Chonetes verneuilianus
Composita subtilita
Enteletes hemiplicata
Meekella striatocostata
Orthotetes crassus
Productus cora
Productus costatus
Productus (Marginifera) longispinus
Productus (Pustula) nebrascensis
Productus pertenuis
Productus semireticulatus
Pugnax uta
Spirifer cameratus
Spiriferina kentuckiensis
Allorisma subcuneata
Allorisma terminale
Avicula longa
Aviculopecten whitei
Aviculopinna americana
Entolium aviculatum
Myalina kansasensis
Myalina perattenuata
Myalina subquadrata
Myalina swallovi
Bellerophon percarinatus
Bucanopsis montfortiana
Naticopsis altonensis
Orthonema subeniatum
Phanerotrema grayvillensis
Spherodoma primigenia
Platyceras parvum
Orthoceras rushense
Phillipsia major

Shale between Tarkio and Preston limestones.
No fossils are reported.

Preston limestone.
Fossil fragments are found, but no species are recognized.

THE SHAWNEE STAGE.

Scranton shale.[21]
Zeacrinus (plates)
Fistulipora
Rhombopora
Ambocoelia planoconvexa
Productus cora
Productus (Marginifera) longispinus
Productus (Pustula) nebrascensis
Productus semireticulatus
Spiriferina kentuckiensis
Straparollus catilloides

Scranton shale and Howard limestone.[22]
Fusulina cylindrica
Lophophyllum profundum
Lophophyllum distortum
Ceriocrinus hemisphericus
Erisocrinus typus
Eupachycrinus tuberculatus

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[20]This is a combination of three lists reported as follows: Samuel Calvin, Geology of Page County: Iowa Geol. Survey, Vol. XI, p. 432. George L. Smith, Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 633; and The Paleontology and Stratigraphy of the Upper Carboniferous of Iowa: Proc. Iowa. Acad. Sci., Vol. XXII, p. 281. J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 150 (Section XVI), and p. 154 (Section XIX, number 6).

[21]Samuel Calvin, Geology of Page County: Iowa Geol. Survey, Vol. XI, p. 429.

[22]George L. Smith, The Paleontology and Stratigraphy of the Upper Carboniferous of Iowa: Proc. Iowa Acad. Sci., Vol. XXII, p. 281; Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 633. J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 146 (No. 16), p. 147 (No. 9).

Hydreionocrinus acanthoporus
Hydreionocrinus mucrospinus
Serpula insista
Fenestella perelegans
Fistulipora nodulifera
Pinnatopora trilineata
Polypora crassa
Polypora elliptica
Polypora submarginata
Rhombopora lepidodendroides
Septopora biserialis
Stenopora carbonaria
Ambocoelia planoconvexa
Chonetes geinitzianus
Chonetes granulifer
Chonetes variolatus
Composita subtilita
Dielasma bovidens
Enteletes hemiplicata
Hustedia mormoni
Marginifera longispina
Meekella striatocostata
Orthotetes crassus
Productus cora
Productus (Pustula) nebrascensis
Productus pertenuis
Productus punctatus
Productus semireticulatus
Pugnax uta
Rhipidomella pecosi
Spirifer cameratus
Spiriferina kentuckiensis
Allorisma terminale
Allorisma granosum
Aviculopinna peracuta
Aviculopecten occidentalis
Aviculopecten whitei
Edmondia nebrascensis
Myalina perattenuata
Myalina recurvirostris
Myalina subquadrata
Myalina swallovi
Nucula ventricosa
Leda bellistriata
Bellerophon percarinatus
Bucanopsis montfortiana
Euomphalus catilloides
Euphemus carbonarius
Phanerotrema grayvillensis
Soleniscus paludinæformis
Worthenia tabulata
Orthoceras rushense
Tainoceras occidentale
Griffithides scitula
Agassizodus variabilis
Peripristis semicircularis
Conostychus broadheadi
Conostychus ornatus
Carpolithes granularis

Severy shale.[23]

Lophophyllum profundum
Fenestella?
Rhombopora lepidodendroides
Septopora biserialis
Scaphiocrinus?
Zeacrinus?
Archaeocidaris aculeata
Ambocoelia planoconvexa
Chonetes granulifer
Composita subtilita
Dielasma bovidens
Enteletes hemiplicata
Orthotetes crassus
Marginifera longispina
Productus (Pustula) nebrascensis
Productus pertenuis
Productus cora
Productus punctatus
Spirifer cameratus
Spiriferina kentuckiensis
Allorisma subcuneata
Allorisma granosum
Aviculopecten
Edmondia nebrascensis?
Modiola subelliptica?
Myalina subquadrata
Nucula
Pinna
Schizodus?
Bellerophon carbonarius
Bellerophon percarinatus
Euomphalus catilloides
Euomphalus rugosus
Euphemus carbonarius
Murchisonia
Phanerotrema grayvillensis
Cythere
Alethopteris grandini
Annularia sphenophylloides
Asterophyllites equisetiformis
Calamites suckowii
Neuropteris ovata
Neuropteris scheuchzeri
Pecopteris cyathea

Topeka limestone—Calhoun shale—Deer Creek limestone.[24]

Fusulina cylindrica
Lophophyllum profundum

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[23]George L. Smith, The Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, pp. 622 and 633; Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. XXII, p. 282. J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, pp. 144-145 (Section X, numbers 9-13).

[24]George L. Smith, Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, p. 88; and Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 637.

From conference in the field it was learned that Doctor Smith had made his collections from the Deer Creek (Forbes) limestone, Calhoun shale and Topeka (Meadow) limestone,

Ceriocrinus hemisphericus
Eupachycrinus tuberculatum
Hydreionocrinus mucrospinus
Archaeocidaris agassizi
Archaeocidaris dininni
Archaeocidaris hallana
Archaeocidaris triseriata
Fenestella tenax
Fistulipora nodulifera
Polypora submarginata
Rhombopora lepidodendroides
Septopora biserialis
Ambocoelia planoconvexa
Chonetes granulifer
Chonetes verneuiliana
Composita subtilita
Dielasma bovidens
Enteletes hemiplicata
Hustedia mormoni
Marginifera longispina
Meekella striatocostata
Orthotetes crassus
Productus cora
Productus costatus
Productus (Pustula) nebrascensis
Productus semireticularis
Pugnax uta
Reticularia perplexa
Rhipidomella pecosi
Spirifer cameratus
Spiriferina kentuckiensis
Squamularia perplexa
Allorisma terminale
Allorisma subcuneata
Chaenomya minnehaha
Myalina swallovi
Macrodon tenuistriatus
Schizodus wheeleri
Bellerophon carbonarius
Bellerophon percarinatus
Euomphalus catilloides
Euphemus carbonarius
Pleurotomaria
Platyceras parvum
Soleniscus intercalaris
Orthoceras knoxense

Calhoun shale.[25]

Archaeocidaris (spines)
Eupachycrinus verrucosus
Scarpiocrinus (plates)
Fistulipora nodulifera
Polypora submarginata
Chonetes granulifer
Discina convexa
Orthotetes crassus
Productus cora
Productus nebrascensis
Productus punctatus
Productus semireticulatus
Spirifer cameratus
Aviculopecten
Edmondia
Entolium aviculatum
Myalina subquadrata
Myalina recurvirostris
Pinna peracuta?
Pseudomonotis hawni
Bellerophon carbonaria
Euomphalus rugosus
Pleurotomaria

Deer Creek (Hawleyville) limestone.[26]

Fusulina cylindrica
Archaeocidaris
Crinoidea (stems and plates)
Fistulipora nodulifera
Rhombopora lepidodendroides
Septopora biserialis?
Ambocoelia planoconvexa
Composita subtilita
Chonetes granulifer
Chonetes verneuilianus
Dielasma bovidens
Hustedia mormoni
Marginifera longispina
Orthotetes crassus
Orthotetes robustus
Productus semireticulatus
Productus cora
Productus costatus
Productus (Pustula) nebrascensis
Productus symmetricus
Rhipidomella pecosi
Pugnax uta
Spirifer cameratus
Spiriferina cristata
Aviculopecten?
Bellerophon carbonarius
Euomphalus rugosus?

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chiefly near the mouth of the ravine (Pilot creek) north of Stennett, and that he had not collected from fossiliferous horizons at a considerable distance (about two-thirds of a mile) up the creek, where the Severy shale members (Union and Louisville limestone) appear in the bed of the creek.

In the Geology of Montgomery County: Iowa Geol. Survey, Vol. IV, Plate XI (opposite page 392), is a picture of the Fate Quarry, near Stennett, in which the top of the Deer Creek limestone appears in the base of the quarry, the Topeka (Meadow) in the center, and fragments of the Severy (Union) near the top, as shown in the picture. This quarry was located on the west side of the Nishnabotna; Pilot creek is on the east side of the river.

25J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, pp. 138, 139, 141, 142: Section V, numbers 11-13, Section VI, numbers 8-9, and Section VIII, number 2.

26Samuel Calvin, Geology of Page County: Iowa Geol. Survey, Vol. XI, pp. 423 and 425. Also, J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, pp. 139-146. The following are considered Deer Creek: Section V, numbers 3-10; Section VI, numbers 1-7; Section IX, numbers 5-8.

Strapatollus catilloides
Phillipsia

Tecumseh shale.
No fossils are reported.

Lecompton limestone (Cedar Creek and Cullom limestones).[27]

Cedar Creek limestone
Fusulina cylindrica
Campophyllum torquium
Lophophyllum profundum
Archaeocidaris
Erisocrinus typus?
Rhombopora lepidodendroides
Fistulipora nodulifera
Ambocoelia planoconvexa
Composita subtilita
Chonetes granulifer
Chonetes geinitzianus
Marginifera longispina
Orthotetes crassus
Productus cora
Productus costatus
Productus (Pustula) nebrascensis
Productus pertenuis
Spirifer cameratus
Aviculopecten
Pinna peracuta
Bellerophon carbonaria
Peripristis semicircularis

Cullom limestone
Fusulina cylindrica

Kanwaka shale.
There is no distinct list of fossils.[28]

THE DOUGLAS STAGE.[29]

Oread limestone.
Fusulina cylindrica (very many, and large)
Lophophyllum profundum
Chonetes granulifer
Productus cora
Spirifer cameratus

Lawrence shale.
Lophophyllum profundum
Crinoid stems
Chonetes granulifer
Productus (Pustula) nebrascensis
Productus cora
Spirifer cameratus

Iatan limestone.
Crinoid stems
Chonetes granulifer
Productus cora
Productus (Pustula) nebrascensis

Weston shale.
Productus nebrascensis
There are few fossils.

LANSING STAGE.[29]

Stanton limestone.
Crinoid stems
Productus (Pustula) nebrascensis
Productus cora
Spirifer cameratus
Alga-like markings

Vilas shale.
No fossils are reported.

Plattsburg limestone.
Fusulina cylindrica
Echinoid spines
Lophophyllum profundum
Composita subtilita
Chonetes granulifer
Orthotetes crassus
Productus (Pustula) nebrascensis

Lane shale.
Crinoid stems

27J. A. Udden, Geology of Pottawattamie County: Iowa Geol. Survey, Vol. XI, pp. 221-224. The exposures are small and distant from each other and from other outcrops. The following are considered Cedar Creek: numbers 4 and 5 of Thomkin's quarry section, numbers 4-6 of Martin's quarry section, numbers 1-3 of Bryant's quarry section, number 1 at river bed south of Carson, and numbers 4-6 of Snapp's quarry section. The following are considered Cullom: number 1 of Thomkin's quarry section, and numbers 1-3 of Martin's quarry section. Geology of Mills and Fremont Connties: Iowa Geol. Survey, Vol. XIII, p. 138, (Section IV, number 2).

28George L. Smith lists seven fossils from the Platte shales, but these shales seem to include the Lecompton (Cullom and Cedar Creek) limestone. "Contributions to the Geology of Southwestern Iowa," Proc. Iowa Acad. Sci., Vol. XXIII, p. 88.

29Exhaustive lists of fossils from the Douglas and Lansing stages in Iowa have not been prepared. Such lists for Missouri may be found in the following reference: Hinds and Greene, Stratigraphy of the Pennsylvanian Series in Missouri: Missouri Bur. Mines, Bull. XIII, pp. 286-288 and 292-295.

KANSAS CITY STAGE.[30]

Iola limestone.
- Lophophyllum proliferum
- Crinoids (stems)
- Bryozoa
- Chonetes verneuilianus
- Orthotetes crassus
- Productus

Chanute shale.
- Bryozoa
- Chonetes verneuilianus
- Composita subtilita
- Productus cora

Westerville limestone (DeKalb).
- Lophophyllum proliferum
- Crinoids (stems)
- Fenestella
- Aulopora
- Chonetes verneuilianus
- Composita subtilita
- Productus cora
- Productus costatus
- Spirifer cameratus
- Straparollus subquadratus

De Kalb limestone.
- Lophophyllum proliferum
- Crinoids (stems)
- Echinoid spines
- Bryozoa
- Composita subtilita
- Dielasma bovidens
- Marginifera longispina
- Orthotetes crassus
- Productus costatus
- Productus semireticulatus
- Spirifer cameratus
- Spiriferina kentuckiensis

Cherryvale shale.
- Rhombopora lepidodendroides
- Eupachycrinus verrucosus
- Chonetes verneuilianus
- Composita subtilita
- Marginifera longispina
- Orthotetes crassus
- Productus cora
- Products (Pustula) nebrascensis
- Spirifer cameratus
- Spirifer planoconvexus
- Aviculopecten occidentalis
- Myalina kansasensis
- Myalina subquadrata
- Myalina swallovi

Winterset limestone.
- Chonetes verneuilianus
- Composita subtilita
- Meekella striatocostata
- Hustedia mormoni
- Productus cora
- Productus costatus
- Spirifer cameratus

Galesburg shale.
- Fusulina cylindrica
- Chonetes verneuilianus
- Composita subtilita

Bethany Falls (Earlham) limestone.
- Fusulina cylindrica
- Lophophyllum proliferum
- Archaeocidaris (plates)
- Zeacrinus (plates)
- Crinoidea (stems)
- Bryozoa
- Composita subtilita
- Chonetes verneuilianus
- Hustedia mormoni
- Marginifera longispina
- Meekella striatocostata
- Productus cora
- Productus costatus
- Productus punctatus
- Spirifer cameratus
- Spiriferina kentuckiensis
- Allorisma subcuneata
- Phillipsia

Ladore shale.
- No fossils are reported.

Hertha limestone.
- Composita subtilita
- Spirifer cameratus
- Spiriferina kentuckiensis

The Cross Section Along Missouri River.

The cross section along Missouri river begins at Hamburg, Fremont county, in the southwest corner of the state, and proceeds northward to Crescent, seven miles north of Council

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[30]These lists are from reports in the Iowa Geological Survey on the different members of the Kansas City stage, and from field notes by the writer: Madison county (Vol. VII), Decatur county (Vol. VIII) and Clarke county (Vol. XXVII). The lists given for Guthrie county are not included, as the strata there belong to the Des Moines series. See John L. Tilton, "The Strata near Stuart, Iowa": Bulletin of the Geological Society of America, Vol. XXXIII, p. 153, 1922. Elsewhere there is uncertainty as to the real source of the fossils referred to the Hertha. Only those are permitted in the above list that are also found in Hinds and Greene's report on The Stratigraphy of the Pennsylvanian Series in Missouri, table opposite page 282.

Bluffs, which is the location of the last known outcrop of Missouri series strata.

The section at the high school[31] at Hamburg, is as follows:

		Feet	Inches
4.	Sandstone, coarse		3
3.	Shale, divided in the middle by a hard band, three inches thick	15	
2.	Limestone, arenaceous		9
1.	Shale	5	
		21	

The limestone is 929 feet above sea level, or 16 feet above the Chicago, Burlington and Quincy railroad track at the station, and 29 feet above Nishnabotna river. The outcrop is closely related to the series found two miles northeast at McKissick grove, and to the face of the clay pit at the brick yard south of Nebraska City,[32] at a distance of about ten miles to the northwest, which is the location of an outcrop and well record used in the cross section from Hamburg to Leon.

Northward along the bluffs bordering the east side of the valley of Missouri river all is concealed by river deposits, drift and loess, which fill a preglacial valley eroded in Missouri series strata, for a distance of thirteen miles to a point three miles south of Thurman. Here in the northwest quarter of the northwest quarter of section 12 appears a three-foot bed of limestone that has the same peculiar characteristics and relation to strata above and below as has the limestone member, No. 2, at the high school at Hamburg, and that, No. 17, in the strata at McKissick grove. The section here found is as follows, as described by Udden,[33] with modifications:

		Feet
9.	Limestone, bluish gray, of fine texture, arenaceous	½
8.	Shale, gray, not calcareous, part originally a black shale; grading into reddish shale above	10
7.	Limestone, blotched, jointed, numerous calcareous lumps up to one-half inch in diameter; a few shell fragments, joints of crinoid stems, and quartz grains	3
6.	Shale, bluish gray, soft; partly concealed	2
5.	Sandstone, grayish blue, of fine texture, calcareous; ripple bedded above	3
4.	Shale, not well exposed	1
3.	Not exposed	4

31G. L. Smith, Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 641.

32For statement of depth of buried channel near Nebraska City, see J. E. Todd, Bull. 158 U. S. Geol. Survey, p. 148.

33J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 150.

2.	Limestone	3
1.	Shale, gray	?
		26½

The uppermost limestone, No. 9, and the limestone, No. 7, a few feet below it outcrop along the hillside from this point to the mouth of Plum creek at Thurman. They also appear in the hillsides along the lower course of Plum creek and north of Thurman for about a mile along Missouri valley, just beyond which point there is a sudden and complete change in strata. This is at a point where Todd[34] recognized the presence of a fault, and where later Smith[35] found further evidence of it. This fault was later called by Tilton[36] the Thurman-Wilson fault and was traced by him across Montgomery, Cass and Adair counties, and into Dallas county. It was found to have but little difference in the amount of displacement.

Near the center of the north line of section 35, Scott township, Udden[37] obtained the following composite section, in which the fourth member from the bottom, a hard blue jointed limestone with small granules, is the stratum especially noted as No. 7, three miles south of Thurman, and also as No. 2, at the high school at Hamburg, and No. 17 at McKissick grove:

		FEET	INCHES
9.	Limestone, weathered brown; many joints of crinoid stems	?	
8.	Shale, chocolate colored, arenaceous, calcareous and micaceous; small gray calcareous nodules	3	6
7.	Shale, yellow, calcareous; with nodules	5	
6.	Shale, gray, calcareous, very fossiliferous: *Lophophyllum proliferum (?)*, *Fistulipora nodulifera* (flattened), *Rhombopora lepidodendroides*, *Septopora biseralis*, *Polypora submarginata (?)*, *Fenestella (?)*, *Chonetes granulifer*, *Ch. verneuilianus*, *Spirifer cameratus*, *Spiriferina kentuckiensis*, *Pugnax uta*, *Syntrielasma hemiplicata*, *Ambocelia planoconvexa*, *Productus semireticulatus*, *Murchisonia (?)*, *Nucula(?)*, denticles of brown color	1	
5.	Limestone, gray, organic fragments in almost structureless matrix		7

34J. E. Todd, On the Folding of the Carboniferous Strata in Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. I, Part 1 p. 61, 1889; also, Some Variant Conclusions in Iowa Geology: Idem, Vol. XIII, p. 184, 1906.

35G. L. Smith, Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 612, 1909.

36John L. Tilton, The Thurman-Wilson Fault through Southwestern Iowa, and its Bearing: The Journal of Geology, Vol. XXVII, 1919; Geology of Cass County and Geology of Adair County: Iowa Geol. Survey, Vol. XXVII; The Strata near Stuart, Iowa: Bull. Geol. Soc. America, Vol. XXXIII, p. 153, 1922. See also footnote 1a, page 228, this volume.

37Geology of Mills and Fremont Counties: Iowa Geol Survey, Vol. XIII, pp. 148, 149.

4. Limestone, blue, dense, jointed, with indistinct small granules; many crinoid stems and a few *Fusulina*	1	
3. Shale, red, containing quartz, mica, and gray calcareous concretions	2	
2. Shale, grayish blue, arenaceous, with some mica	6	
1. Shale, red		6
	19	7

As quarrying has not been carried on for many years the above described section is not at present easily obtainable, but with the aid of Mr. Martens, the owner, the sites of former quarries were traced along the hillside. The character of the fragments of limestone was noted as was also the presence of a bed of reddish shale about eight feet thick which lies above the beds of limestone formerly quarried. These conditions were noted northward to the northwest quarter of the southeast quarter of section 26 and to the northwest quarter of the northeast quarter of section 25, beyond which no evidence whatever of the presence of these strata was found.

To the north of the above described exposure and just south of where a road turns west past Wabonsie lake, the thick Topeka (Meadow) limestone appears high in the bluff, below which appears the Deer Creek (Forbes) with its dark chert and shale.

Between the two locations above described lies the fault, the location of which is thus correctly determined within a distance of three hundred feet. Here the strata change suddenly from the limestone in the McKissisk Grove shale and above the Nyman coal on the south (downthrow) side of the fault, to the Deer Creek limestone and shale north of the fault (upthrow side), a displacement of about three hundred feet as computed by Smith.[38]

North of the region above described the Deer Creek beds appear along the road in section 14 of the same township, and farther north to the center of section 10 of Lyons township, Mills county (Township 71 north, Range 43 west, opposite Haynies station), a distance of eight miles, there is an almost continuous series of exposures. The following section may be found between sections 25 and 26 of Lyons township (Township

[38]Iowa Geol. Survey, Vol. XIX, pp. 647-648.

71 north, Range 43 west), at the quarry near a large stone house.

		FEET	INCHES
21.	Limestone, weathered, but of a character formerly similar to the next limestone below	1	3
20.	Limestone, dark gray, with beds of chert; *Productus nebrascensis, Phillipsia*	3	
19.	Limestone, yellowish gray, shaly; *Productus nebrascensis*, Bryozoa	1	
18.	Shale, argillaceous and calcareous, with cherty divisions; crinoid stems	9	3
	(Topeka [Meadow], 14 feet, 6 inches).		
17.	Limestone, divided into two portions by shaly parting in center; lower portion very cherty with both dark and light colored chert	2	2
16.	Shale, gray below, grading into limestone above; fossiliferous	1	2
15.	Limestone, gray, very fossiliferous at top and at bottom		5
14.	Shale, light blue in center, drab in upper four inches, and black in lowest four inches	1	8
13.	Limestone, gray; fragments of fossils	1	3
12.	Shale, light blue, clayey; not fossiliferous	1	4
11.	Limestone, dense	2	7
10.	Limestone, dense; *Hustedia mormoni*	3	
9.	Concealed, but apparently shale; about	7	
	(Forbes [Deer Creek], 20 feet 7 inches).		
8.	Limestone, gray, jointed; *Productus semireticulatus*, Crinoid stems		11
7.	Shale, dark, clayey	1	10
6.	Limestone, gray; fossil fragments	2	
5.	Limestone, gray, in two equal parts; many fossil fragments	1	
4.	Shale, gray, clayey above to near bottom where it is arenaceous	8	6
3.	Limestone, arenaceous	1	1
2.	Sandstone, light yellow	5	5
1.	Shale, blue, above a gray calcareous shale; only partly exposed down to level of road (which is about 982 feet above sea level)	12	
	(Lecompton [Cedar Creek and Cullom], 32 feet, 9 inches).		
		67	10

The level of the road at the old stone house is 982 feet above sea level and 37 feet above the Chicago, Burlington and Quincy railroad crossing west. The strata in the interval from the level of the road to the level of the river are not exposed, but it is evident that the Oread (Plattsmouth) limestone belongs in this interval.

For a distance of four miles straight away, or of six miles by the road along the bluff, to where the road crosses Keg Creek near Mills station, no stratified rock appears. At the location mentioned, the northeast quarter of the northeast quarter of section 27, Glenwood township,[39] there is an outcrop of a portion of the Oread (Plattsmouth) limestone by the side of the creek, as follows:

	FEET
Limestone in layers of various thicknesses up to nine inches, with chert; many *Fusulina* and many fossil fragments; lowest stratum is jointed, and striated (Oread limestone).	8

The bed of the creek is here at a level of 938 feet above sea level, and 18.75 feet below the railroad at Pacific Junction.

At Glenwood there is a deep well, a condensed record of which is as follows[40]:

	THICKNESS FEET	DEPTH FEET
Quaternary and recent deposits (175 feet thick, top of well 1,132 feet above sea level)	175	175
Missouri and Des Moines series of Pennsylvanian (thickness, 1,060 feet)—		
Limestone, soft, light and darker gray, cherty	2	177
Limestone, dark blue, argillaceous, pyritiferous	10	187
Shale, black, carbonaceous	1½	188½
Clay, blue, shaly	6½	195
Shale, iron-gray	8	203
Limestone, gray; earthy luster	24	227
Shale, dark blue gray, fissile; discs of crinoid stems and fragments of *Productus*	5	232
Limestone, gray, luster earthy, compact, moderately hard; with crinoid stems, echinoid spines, and fragments of brachiopods	8	240
Shale, black, carbonaceous	4	244
Limestone, soft, yellow-gray; with *Fusulina*	13	257
Shale, blue	7	264
Limestone, light yellow, fossiliferous	9	273
Shale, dark red	16	289
Limestone, brecciated; sample consists of two large unfractured masses of very hard limestone breccia; limestone gray or reddish; matrix greenish gray and argillaceous, but hard	25	314
Sandstone	9	323
Limestone, argillaceous, bluish gray	17	340
Shale, blue	2	342
Limestone, compact	5	347
Shale, greenish gray, arenaceous, calcareous	3	350
Limestone, hard, gray, highly cherty at 358 feet	13	363
Shale, hard, greenish gray, highly calcareous	10	373
Limestone, light greenish gray, highly argillaceous	5	378
Limestone, light yellow, compact, fine grained	18	396
Shale, black, carbonaceous; and greenish gray, hard	9	405
Marl, white	2	407
Limestone, hard, gray	8	415
Shale, gray; with limestone, argillaceous	4	419
Shale, varicolored	19	438

39Township 72 North, Range 43 West.

40Condensed from W. H. Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, pp. 1139-1140.

		FEET	INCHES
Limestone, gray, close textured	18	456	
Limestone, hard, blue, highly argillaceous; crinoid stems and fragments of brachiopods	11	467	
Shale, black, carbonaceous; impure gray limestone	3	470	
Sandstone	6	476	
Limestone, white and light gray, close textured, earthy luster	15	491	
Shale, black	5	496	
Limestone, yellow-gray, fossiliferous, crystalline to earthy	12	508	
Shale, dark and greenish gray, with *Chonetes*	11	519	
Limestone, light yellow-gray, soft, fossiliferous	10	529	
Shale, green, calcareous	21	550	
Limestone, white, soft, crystalline to earthy	20	570	
Shale, gray, highly calcareous, fossiliferous	10	580	
Shale, dark, carbonaceous	15	595	
Limestone, white and light colored; in places fossiliferous, with one foot of coal (?) at 612 feet, and brown chert at 635 feet	43	638	
Shale, varicolored, arenaceous, with minute angular fragments of limpid quartz	47	685	
Sandstone, greenish gray, close and fine grained, argillaceous and calcareous; some siliceous limestone, hard, subconchoidal fracture; with much shale at 706 and 711 feet; vein of salt water at 716 feet	35	720	
Coal and black shale	1	721	
Shale, blue	4	725	
Limestone, gray, hard; fracture subconchoidal, close textured, fossiliferous and flinty at 732 feet; 4 feet of blue shale at 730 feet	15	740	
Other strata to the top of the Mississippian	495	1,235	
Mississippian:			
Strata to bottom of well	765	2,000	

Six miles north of Keg creek along the bluff road there is an exposure of stratified rock which is about half a mile south of Henton station. There is a second outcrop just above Henton station. The section described by Udden[41] is located in the northwest quarter of the northwest quarter of section 29 (Township 73 North, Range XLIII west). It is as follows:

		FEET
4.	Shale, gray with thin calcareous layers and occasional calcareous concretions from one to two inches in diameter; denticles of annelids, minute conical teeth, and a small *Productus*	2
3.	Limestone, yellow or gray	1½
2.	Limestone, gray or cream colored, cherty, minute oölitic grains and fragments of shells, a few small grains of iron pyrites	1
1.	Limestone, light bluish gray, in heavy ledges with some shaly layers and with irregular nodules of chert and minute oölitic grains. Between the lower courses are dark carbonaceous seams containing brachiopods, sponge spicules, spinese of crinoids and of *Archaeocidaris* and	

41J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, pp. 135-136.

Fucoid-like impressions; *Erisocrinus typus, Eupachycrinus verrucosus, Fistulipora nodulifera, Rhombopora lepidodendroides, Ambocelia planoconvexa, Chonetes granulifer, Orthotetes crassus, Productus cora, P. costatus, P. pertenuis, Composita subtilita, Spirifer cameratus, Allorisma subcuneata, Chaenomya leavenworthensis, Ch. minnehaha, Solenomya (?), Pinna peracuta, Bellerophon* (large) and other gasteropods	3
	7½

The base of the section is close to the level of the railroad track, which is here 963 feet above sea level.

In the list of fossils the large proportion of pelecypods and crinoids is noteworthy. The writer is classifying the section as a part of the Lansing stage (Stanton limestone). It is clearly below the Oread limestone, suggests the Weeping Water limestone of Nebraska, and may help to fix the Weeping Water in its proper place in the geologic column as recognized in Missouri and Iowa.

White[42] described an exposure in the valley of Mosquito creek that is not now available, and Udden in his report on the Geology of Pottawattamie county[43] mentions the outcrop as follows: "On the left bank of Mosquito creek, near the center of the west line of section 21, Township 75 north, Range XLVII west, there are some excavations which were made in quarrying limestone many years ago. The strata are not now well exposed and no quarrying has been done for many years. In White's report the rock is described as consisting of about seven feet of limestone with marly partings. Some of the upper layers are said to have been flinty. From specimens picked up on the site of the quarry it appears that the limestone of this place is of two kinds. One chip consisted of indurated, calcareous, fragmental rock of fine texture in which the fragments are largely composed of some organic structure. These are more or less rounded by trituration, and are sometimes surrounded by a thin accretive crust of structureless calcite, and then resemble incipient oölitic grains. The other type of limestone represented in the fragments likewise had a clastic, compact structure, in which larger fragments of shells and joints of crinoid stems are firmly imbedded in a

[42]C. A. White, Geology of Iowa, Vol. 1, p. 379, 1870.

[43]J. A. Udden, Geology of Pottawattamie County: Iowa Geol. Survey, Vol. XI, p. 226, 1900.

copious matrix composed mostly of very minute calcareous particles."

About six miles still farther northwest is located the last of the series of Missouri series strata found in Iowa. Udden[44] describes the condition as follows: "In the southeast quarter of section 27, and in the northeast quarter of section 34, Crescent township, beds of limestone and shale are almost continuously seen at the base of the bluffs of Missouri river for the distance of three-fourths of a mile, rising about twenty feet above the plane of the adjacent bottom land. Some quarrying was done at this place several years ago and the exposures show a succession of beds nearly twenty feet in thickness.

	FEET
5. Limestone, yellowish and gray, in ledges from six inches to one foot in thickness, compact near the base, in some parts brecciated and in others having a finely oölitic texture. A polished specimen of this rock is seen to consist of rounded and incrusted calcareous fragments imbedded in a matrix of almost transparent crystalline calcite. The fragments are of different sizes. Some have a diameter of nearly a millimeter, and these are mingled with others of about one-fifth that diameter. Most appear elliptical in section. Some of the large fragments have a nucleus with a structure like a fragment of *Striatopora*. A few still larger fragments are pieces of small shells. This specimen also exhibits several small, crooked joints or fissure veins filled with pure crystalline calcite. Another specimen appears to the unaided eye as an ordinary compact gray limestone, but as seen under a lens it appears to be fragmental, consisting largely of small *Fusulinas*, some of which are surrounded by a thin calcareous crust. These, together with finer fragmental material, are imbedded in a structureless calcareous matrix. In some cases the fragments are welded together as if by partial solution and redeposition of this substance. Minute crevices and veins filled with crystalline calcite are abundant everywhere. There are also abundant plain evidences of small faulting and brecciation by fracture	5
4. Shale, yellow	2
3. Limestone, yellowish gray, with occasional *Fusulinas*, compact in texture above but locally oölitic below, in some places quite soft. Contains *Allorisma subcuneata*	2
2. Shale, blue, with numerous fossils and occasional crystals of selenite. The fossils observed were: *Fusulina cylindrica* (small size), *Archaeocidaris triseriata*, *Eupachycrinus verrucosus*, *Erisocrinus typus*, *Fistulipora nodulifera*, *Rhombopora lepidodendroides*, *Chonetes granulifer*, *Meekella striatocostata*, *Productus cora*, *P. costatus*, *P. nebrascensis*, *Composita subtilita*, *Spirifer cameratus* (large)	5
1. A simple massive ledge of fine-grained oölitic limestone, seen	

44Idem, pages 227-228.

to contain pieces of *Chenomya*, *Bakevillia illinoiensis* (?), and having on its upper surface partly imbedded, *Axophyllum rude*, *Lophophyllum proliferum*, *Composita subtilita*, *Productus cora*, and numerous crinoid stems. In a thin section of the rock in this ledge the oölitic spherules are seen to be imbedded in a transparent matrix of crystalline calcite. They average about one-fourth of a millimeter in diameter and barely fall below the limit of ready recognition to the unaided eye. The microscopic aspect of the rock is that of an ordinary finely granular limestone. Most of the rounded grains are elliptical in section and some of them have a crystalline transparent nucleus. In other cases the nucleus is a minute organic fragment, such as a tiny bit of *Fusulina* or of the joint of a crinoid stem. These nuclei are surrounded by an opaque crust of structureless calcite about one-fortieth of a millimeter in thickness. Exposed 3

17''

Udden[45] further states: "White's statement[46] that the Mosquito creek quarries are in the same ledges as those exposed in the bluff south of Crescent, is corroborated by the observation on the lithological character of the ledges. At both places there is an oölitic limestone of fine texture."

The bottom of the strata above described is 980 feet above sea level.

A projection northward of the sections described from Fremont and Mills counties, but with the lower dip required by the section on Keg creek, the record of the deep well at Glenwood, and the section at Henton, would bring the lowest limestone beds of the Pennsylvanian formations of southeastern Nebraska in line with the strata found at Mosquito creek and near Crescent. The general sequence and character of the strata in the two places seem to correspond. In the present paper they are classed as belonging to the Lansing stage, and probably to the Plattsburg substage.

The next outcrop to the north from Crescent is twenty miles away at Logan, where strata deep down in the Des Moines stage outcrop, the relations of which strata are discussed in the chapter on Areal Distribution.

The Cross Section Along East Nishnabotna River

The cross section along East Nishnabotna river extends from Hamburg, Fremont county, to Lorah, Cass county. It is pos-

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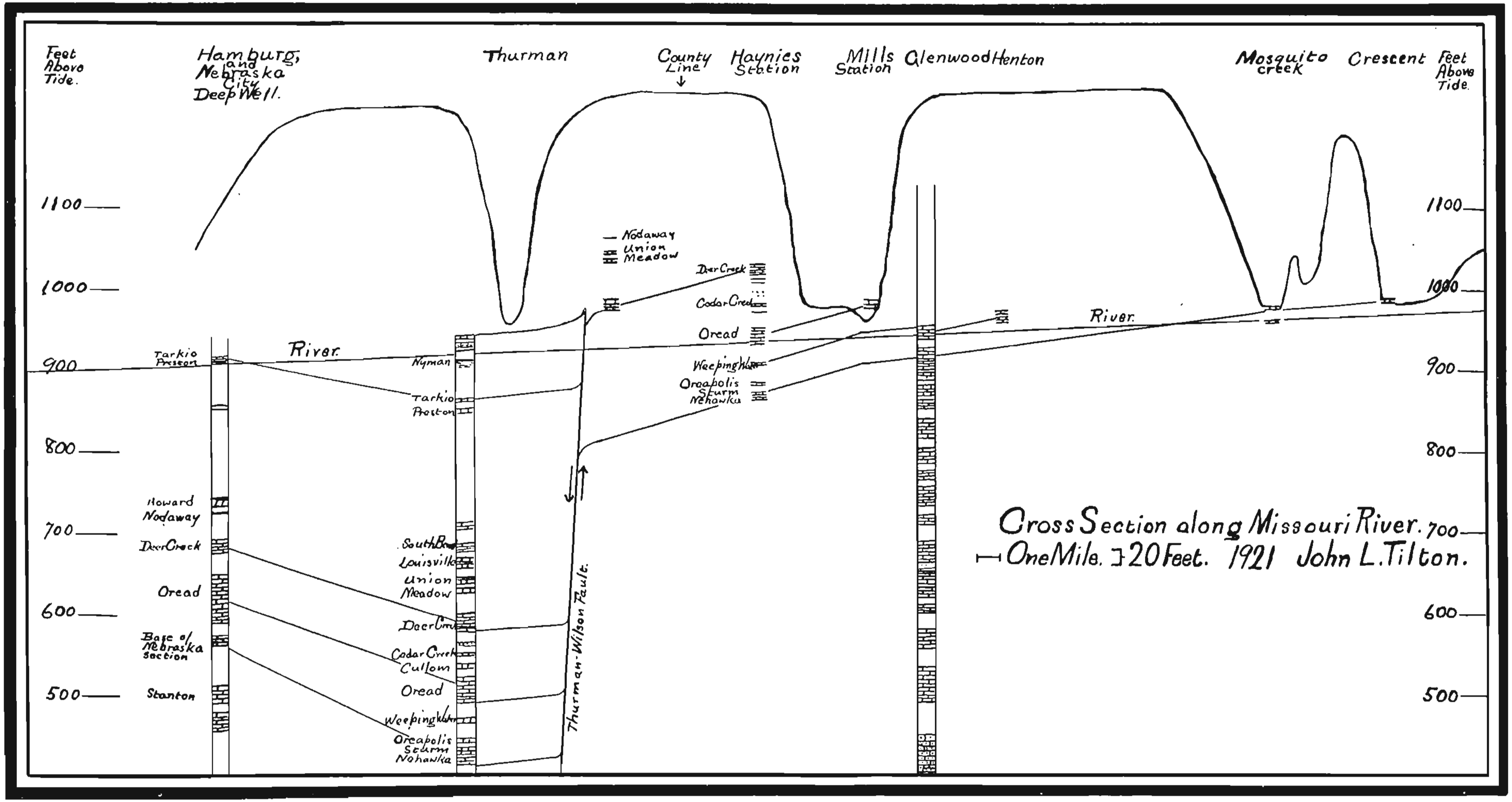
45Idem, page 230.

46Geology of Iowa, Vol. I, p. 379, 1870.



The cross section along Missouri river from Hamburg to Crescent.

sible to obtain the elevation of the river bed above sea level not only at Hamburg and at Lorah, but also at Riverton, Shenandoah, Red Oak, Stennett, Elliott, Griswold, Lewis and Atlantic; and to make use of the descriptions of strata at Hamburg which have been so carefully prepared by Udden and Smith, of those at McKissick grove and Essex prepared by Calvin and Smith, and of those at Stennett, Lewis, Fox quarries, and Turkey creek south of Atlantic prepared by the writer. The record of the outcrop at Hamburg is used also in the cross section northward along Missouri river, and in that eastward to Leon. The various outcrops of strata are referred to the level of water in East Nishnabotna river and drawn in their proper positions above sea level.

Both Udden[47] and Smith[48] give detailed records of strata found at the high school at Hamburg.

		FEET	INCHES
4.	Sandstone, coarse		3
3.	Shale, divided in the middle by a hard band three inches thick	15	
2.	Limestone, arenaceous		9
1.	Shale	5	
		21	

The limestone is 929 feet above sea level, or 16 feet above the Chicago, Burlington and Quincy railroad track at the station, and 29 feet above low water in Nishnabotna river.

These strata Smith refers to the McKissick Grove shale, and correlates the arenaceous limestone, No. 2, with the third layer from the top (No. 17) at McKissick grove, which stratum is characterized by spheroidal lumps about half an inch in diameter.

The McKissick grove series of outcrops extends east and west through section 13 (Township 67 north, Range 42 west), two miles northeast of Hamburg. This section also is described by both Udden[49] and Smith.[50] Smith's description, with slight additional interpretation, is as follows:

47J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 151.

48G. L. Smith, Carboniferous Section in Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 641.

49Idem, pp. 151-154.

50G. L. Smith, Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, p. 80; also Iowa Geol. Survey, Vol. XIX, p. 639.

		Feet	Inches
19.	Shale, blue	12	
18.	Shale, gray, weathered	8	
17.	Limestone, very dark gray, arenaceous, many spheroidal lumps, in places brecciated	1	
16.	Limestone, blue, very arenaceous; might be termed a calcareous sandstone	1	
15.	Shale, arenaceous, micaceous	3	
14.	Sandstone, blue, weathering yellow	6	
13.	Shale, arenaceous, micaceous	2	6
12.	Sandstone, blue, weathering yellow	1	
11.	Shale, gray	9	
10.	Limestone, dark gray, in two layers; fossiliferous	3	
9.	Coal (Nyman)	1	
8.	Shale, yellow and blue	31	
	(McKissick Grove shale, 78 feet, 6 inches)		
7.	Limestone, gray, fossiliferous (Tarkio)		6
6.	Shale, dark gray (Tarkio)	3	6
5.	Limestone, very dark gray (Tarkio)	4	6
	(Tarkio limestone, thickness, 8 feet 6 inches)		
4.	Shale, blue, weathering to yellow	8	
3.	Limestone, weathered brown; in two or three layers	4	
	(Preston limestone, 4 feet)		
	(Total thickness of Wabaunsee stage, 99 feet)		
2.	Shale, gray, weathered	12	
1.	Limestone, dark gray (Fargo)	1	
	(Scranton shale)		
		112	

The lowest stratum is close to the level of the railroad track, which is here seventeen feet above the level of the water in Nishnabotna river near by.

The third outcrop to be used is located two miles southeast of Essex, on Rocky Branch, the northwest quarter of the southeast quarter of section 36, Township 70 north, Range XXXIX west. It is described and interpreted by Smith as follows, page 635, Vol. XIX, Iowa Geological Survey:

	Feet	Inches
Limestone, *Fusulina*	1	
Shale	3	
Limestone, soft		8
Shale		6
Limestone, blue	1	4
(Tarkio limestone and included shale, thickness, 6 feet, 6 inches)		
Shale, calcareous	7	
Limestone, shaly, soft, impure	1	6
(Preston limestone, thickness, 1 foot 6 inches)		
Not exposed, to bed of creek	4	
	19	0

At present but a few scattered fragments of limestone and no exposures of shale are to be seen near either Climax or Coburg, Montgomery county; but Lonsdale[51] gives the following record, the base of the section apparently being close to the bed of Walnut creek, west of Climax:

		FEET	INCHES
6.	Limestone, very fine textured	1	
5.	Shale, in part calcareous	3	
4.	Shale, argillaceous	2	2
3.	Limestone, earthy	1	
2.	Shale, dark gray	1	
1.	Limestone, earthy	1	6
		9	8

The absence of the blue limestone, the shaly and earthy character of the limestone beds which are present, and the higher position of the Tarkio where it is to be seen near Essex with dip to the southwest, make it probable that this limestone at Climax is Preston limestone.[52] Strata of the same horizon outcrop three miles south of Stanton.

A mile southwest of Red Oak a slight exposure may be found at the mouth of a small ravine; southwest quarter of the southwest quarter of section 32, Township 72 north, Range 38 west.

		FEET	INCHES
7.	Limestone, gray; crinoid stems and many fragments of other fossils		11
6.	Shale, gray	2	
5.	Concealed	2	
4.	Limestone; dark blue		6
3.	Concealed		6
2.	Limestone, gray; *Fusulina;* apparently in place		6
1.	Concealed to low water in river	1	
		7	5

Apparently this imperfect exposure is of the Fargo in the top of the Scranton shale, only the upper portion of which limestone appears in the McKissick grove section. What little may be seen corresponds as well as need be expected with the description of the Fargo as found in eastern Nebraska, and fits into the general sequence.

Lonsdale[53] gives the following record of a deep prospect hole at Red Oak.

51E. H. Lonsdale, Geology of Montgomery County: Iowa Geol. Survey, Vol. IV, p. 395.

52Calvin also gives a detailed description of the Preston limestone and associated shale. Geology of Page County: Iowa Geol. Survey, Vol. XI, p. 432.

53E. H. Lonsdale, Geology of Montgomery County: Iowa Geol. Survey, Vol. IV, pp. 396-397.

	Thickness Feet	Thickness Inches	Depth Feet	Depth Inches
Surface deposits	30		30	
Sandstone and shale referred to Cretaceous	64		94	
Missouri stage:				
Shale, siliceous above, marly below	99	6	192	6
Limestone		6	193	
Shale, dark (horizon of Nodaway coal)	5		198	
Limestone	3		201	
Shale, argillaceous	1	6	202	6
Limestone, earthy	5		207	6
Sandstone	8	6	216	
Shale, blue, argillaceous	4		220	
Limestone, gray	3	6	223	6
Shale	6		229	6
Limestone, impure	2	6	232	
Shale, gray above, black at bottom	3	10	235	10
Limestone, in thin ledges	3		238	10
Shale, thin indurated layers in upper part	10	6	249	4
Limestone	1	9	251	1
Limestone, more or less shaly	25		276	1
Limestone	3		279	1
(Base of Deer Creek [Forbes] limestone.)				
Shale, argillaceous	12		291	1
Limestone	13		304	1
Shale, siliceous, dark	10		314	1
Limestone	3		317	1
Shale, gray below, upper four feet bituminous	17	6	334	7
Limestone, gray	2		336	7
Shale, siliceous above, clayey below	10		346	7
Limestone, impure	2	6	349	1
Shale	6	8	355	9
(Bottom of Shawnee stage, top of Douglas.)				
Limestone	23		378	9
(Base of Oread [Plattsmouth] limestone.)				
Shale, argillaceous above, calcareous and sandy below	24		402	9
Limestone, gray	6		408	9
Shale, variegated	73		481	9
Limestone	2		483	9
Shale, siliceous above	12		495	9
Limestone	7	6	503	3
Shale, argillaceous	3		506	3
Limestone	1	6	507	9
Shale	4		511	9
Limestone, marly parting	5		516	9
Shale calcareous, clayey and variegated in lower part	9		525	9
Limestone, gray, impure	14		540	9
(Base of Stanton limestone.)				
Shale	19		558	9
Limestone	3		561	9

It is judged that the dark shale in this record which is reported at a depth of 198 feet is at the horizon of the Nodaway coal. For this correlation and all the other correlations in parentheses in the Missouri series, the writer is responsible. The drilling apparently went to the base of the Lansing stage. It is located south of the fault.

Between the exposure a mile southwest of Red Oak and the one at an old quarry on the west side of Nishnabotna river a little north of west from Red Oak, there is a complete break in the sequence of strata and an abrupt change in dip from the southwest to three degrees and forty-five minutes to the southeast (as measured at Riverview park). The strata at Riverview park,[54] which are located on the same side of the fault as the old quarries named, and but a mile and a quarter farther to the northeast, are characterized by an abundance of *Fusulina cylindrica*, some of the beds containing little else, a condition so pronounced that it cannot be duplicated[55] in any other horizon of the Missouri series in this part of the country. The same strata outcrop on Turkey creek, south of Atlantic in Cass county, in Harrison township in Adair county, and in the bluffs south of Plattsmouth, Nebraska. They are the beds of the Oread limestone. At Riverview park the section found is as follows:

		FEET	INCHES
16.	Loose calcareous fragments	?	
15.	Limestone, decomposed, light greenish		10
14.	Limestone, many *Fusulina*, crinoid stems and fragments of other fossils	1	
13.	Shale, with fragments of fossils		1
12.	Limestone, gray		5
11.	Shale, greenish gray		3
10.	Limestone, light colored flint in places; fossil fragments; limestone weathering to a greenish clay above	1	6
9.	Shale		1
8.	Limestone, gray		8
	Below this plane the limestone is full of *Fusulina cylindrica*.		
7.	Limestone, gray, in three parts, 4 inches at top, 10 inches in center, 7 inches at base; *Fusulina cylindrica*	1	9
6.	Shale, brown		1
5.	Limestone, shaly below; *Fusulina cylindrica*, *Spirifer cameratus*	1	3
4.	Limestone; *Fusulina cylindrica* and echinoid spines		5
3.	Limestone, shaly; crinoid stems		5
2.	Limestone; fossil fragments		8
1.	Not exposed, to low water below dam		10
	(Oread limestone.)		
		10	3

[54]Northwest quarter of the northeast quarter of Section 29, Township 72 North, Range 38 West.

[55]The nearest approach is in the upper part of the DeKalb limestone as seen in Brushy Branch, Madison county.

The Thurman-Wilson fault passes between these ledges of the Oread limestone, which lie on the northwest side of the fault, and the outcrop of Fargo (Scranton) limestone a mile down the river from Red Oak, which is on the south side of the fault.

The Lecompton (Cullom) limestone comes up to the river deposits or to the glacial drift somewhere between Riverview park and the outcrop of the Lecompton (Cedar Creek) limestone that is in the road north on the west side of the river (southwest quarter of the southeast quarter of section 5). The Deer Creek (Forbes) and the Topeka (Meadow) are by the roadside farther north.[56] The next series of sections to be used may be found along a ravine north of Stennett, extending from the southeast quarter of the northeast quarter of section 27, Township 73 north, Range 38 west, eastward a little past the center of section 26. The record of the strata is as follows:

		FEET	INCHES
17.	Limestone, very fossiliferous; crinoid stems, echinoid plates, *Myalina* (three species), *Bellerophon*, *Productus nebrascensis*, Bryozoa (three species)	1	5
16.	Limestone, decomposing; fossil fragments, crinoid stems		9
	(Severy [Louisville limestone], 2 feet 2 inches.)		
15.	Shale, calcareous above, gray below	2	5
14.	Shale, black	1	11
13.	Limestone, gray; *Chonetes*, *Marginifera longispina*, crinoid stems	1	5
12.	Shale, gray, argillaceous		10
11.	Limestone, gray		1
10.	Shale, gray, argillaceous	1	
9.	Limestone, gray		2
8.	Shale, drab		10
	(Severy [Union limestone, with shale above it], thickness, 8 feet, 8 inches.)		
7.	Limestone (forming the bed of the ravine part of the way); *Productus nebrascensis* all through the bed, crinoid stems near top	2	9
6.	Shale, argillaceous, dark		2
5.	Limestone	1	6
	(Topeka limestone [Meadow], and shale above it, thickness, 4 feet, 5 inches.)		
4.	Shale, black	1	4
3.	Shale (?) not exposed	10	
2.	Limestone, in various thicknesses up to 6 inches,		

56In Lonsdale's report on the Geology of Montgomery County: Iowa Geol. Survey, Vol. IV, may be found Plate IV, giving a view of the old Fate Quarry at Stennett. The limestone at the bottom of the picture is the top of the Deer Creek. The Topeka limestone is that through the center, a bed of shale separating it from the Deer Creek. Along the top of the bluff may be seen the fragments of the Severy (Union limestone), separated from the Topeka limestone by a bed of shale.

	FEET	INCHES
with shaly partings; a *Fusulina* limestone in center; one stratum bituminous	8	
(Deer Creek limestone [Forbes] and shale above, thickness, 19 feet, 4 inches.)		
1. Not exposed, to river	8	6
	42	1

Because of the changes in dip related to a low fold paralleling the fault upon the northwest side the Oread is exposed again at Lewis, and the lowest beds with their great abundance of large *Fusulina* appear in the valley of Turkey creek five miles farther to the northeast.

The Spring creek section near Lewis is in the west center of the northwest quarter of section 9, Cass township, Township 75 north, Range 37 west. The part of it which belongs to the Missouri stage is as follows:

	FEET	INCHES
4. Shale, blue in upper portion, then dark reddish brown, then yellowish and soft (yellow ochre), then brownish red	7	6
3. Limestone, gray, full of *Fusulina cylindrica*	5	6
2. Shale, gray	2	
1. Limestone, in thin layers; crinoid stems, *Marginifera muricata*, *Chonetes verneuilianus*, *Composita subtilita*, *Productus nebrascensis*, *Spirifer cameratus* and Bryozoa	4	10
(Oread limestone [Plattsmouth], thickness, 12 feet, 4 inches)		
	19	10

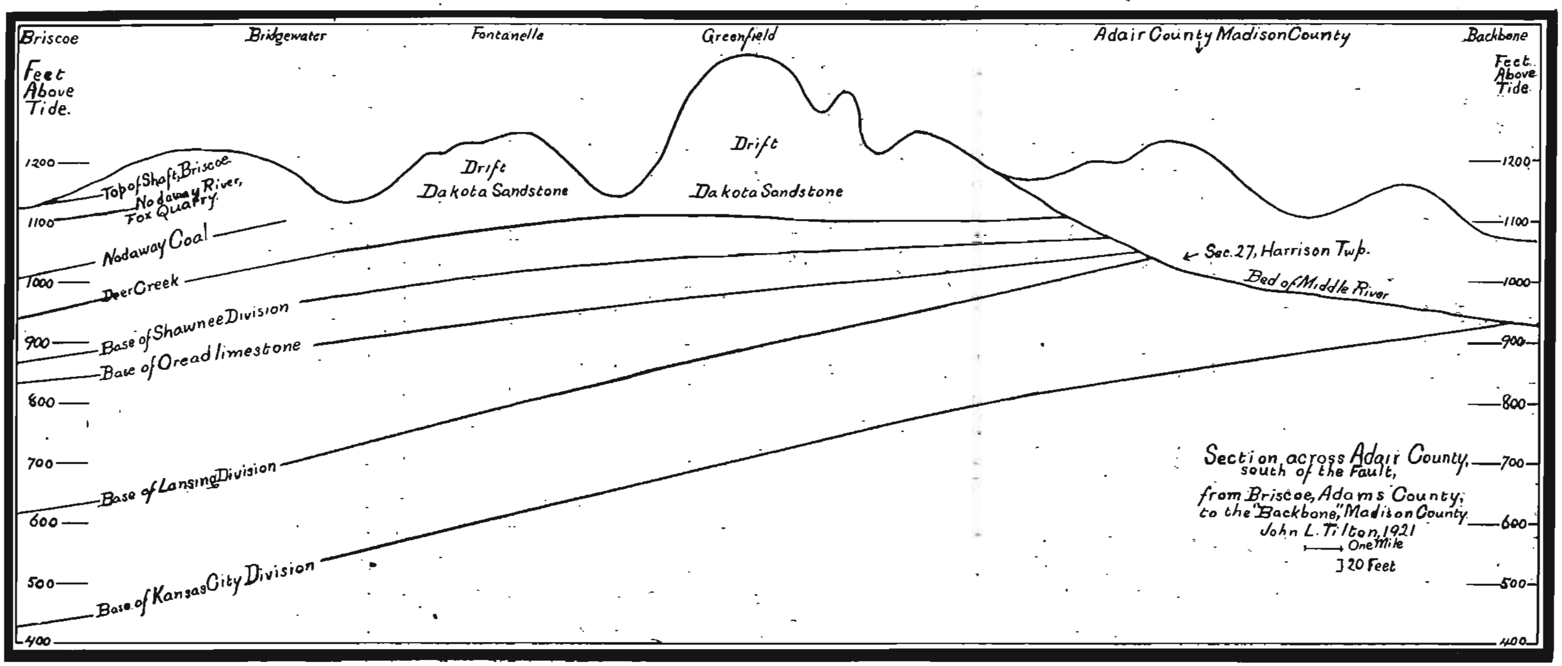
A limestone which is exposed for a thickness of three feet in the side of a ravine in the south half of section 1, Cass township, is a mass of large *Fusulinas*. Across the road to the east an exposure of six inches of this limestone which belongs near the top of the bed and is here thin bedded, is crossed by the creek. Here may be seen crinoid stems, Bryozoa, *Chonetes*, and many fragments not identifiable. All of these beds belong to the Oread limestone.

The prospect hole drilled at Atlantic is located in the northeast quarter of the southeast quarter of section 5, Grove township (Township 76 north, Range XXXVI west). It is published on pages 1121 to 1122 of volume XXI, Iowa Geological Survey, and is reproduced on pages 257 to 258 of the Geology of Cass County: Vol. XXVII, Iowa Geological Survey. The part that has been referred to the Missouri and Des Moines series is as follows, the remainder being condensed:

RECORD OF STRATA IN DEEP WELL AT ATLANTIC, IOWA

	Thickness Feet	Depth Feet
Pleistocene (no sample)	125?	125?
Pennsylvanian (725 feet thick; top, 1,025 feet above sea level)		
Shale, blue	35	160
Shale, gravelly	35	195
Shale, red and blue, gravelly	5	200
Limestone, gray, sandy	15	215
Shale, red and blue, with soapstone	5	220
Shale, gravelly	5	225
Shale, purple, dark drab and green, fine, unctuous; with pebbles (five limestone, one vitreous sandstone and one coal)	35	260
Shale, gravelly	50	310
Clay, mottled red and blue	30	340
Shale, blue	15	355
Shale, red and blue, with gravel	5	360
Shale, blue, with slate	5	365
Sandstone and shale	50	415
Slate, black; soapstone, blue and green	5	420
Shale, varicolored, green and reddish; fissile, practically noncalcareous	10	430
Sandstone	5	435
Shale	15	450
Shale and limestone	15	465
Shale, varicolored, green and reddish; fissile, practically noncalcareous	10	430
Clay and soapstone	15	480
Sandstone	25	505
Shale, blue	12	517
Shale, dark gray, very finely laminated, somewhat calcareous	23	540
Sandstone, or sandy limestone	10	550
Shale, dark gray	15	565
Shale, dark brown-gray, noncalcareous, arenaceous, pyritiferous	20	585
Sandstone, brown, highly ferruginous	5	590
Sandstone	10	600
Shale, sandy	30	630
Sandstone, very fine	30	660
Shale and slate	15	675
Shale, iron gray, finely laminated, noncalcareous	10	685
Sandstone, white, very fine	10	695
Clay, blue, with gravel	15	710
Shale, sandy	15	725
Sandstone	5	730
Shale, finely arenaceous, ocherous, some black	10	740
Shale, black, carbonaceous	10	750
Shale, blue, and slate	10	760
Shale, yellow, gravelly	40	800
Sandstone, gray, of finest grain, with much black shale; samples at 810 and 815	25	825
Limestone, sandy	5	830
Sandstone, brown	5	835
Sandstone, gray, of finest grain, with much black		
Mississippian (top 300 feet above sea level)	420	1,270
Devonian ? (40 feet penetrated; top, 120 feet below sea level)	40	1,310

It is not believed that any of the strata penetrated in this



Section across Adair county, south of the Thurman-Wilson fault, from Briscoe, Adams county, to the "Backbone," Madison county.

well belong to the Missouri series. The fifteen feet of limestone at a depth of 215 feet corresponds to the limestone that outcrops north of Stuart, and the coal at about 260 feet corresponds well with the coal that has been mined at Eureka shaft in Adair county and north of Stuart in Guthrie county, in both of which places the limestone[57] and coal belong deep in the Des Moines stage.

A cross section already published in the Geology of Adair County[58] connects the strata at Briscoe, Adams county, with the strata outcropping along Middle river in eastern Adair and western Madison counties, along a line south of the Thurman-Wilson fault. In the diagram as then published the base of the Deer Creek limestone should have been drawn lower down, so as to outcrop in the center of Harrison township, Adair county. The diagram is here reproduced with modifications.

The Cross Section from Nebraska City, Nebraska, to Decatur City and Leon, Iowa.

The cross section from Nebraska City, Nebraska, to Decatur City and Leon, Iowa, extends east and west along the sixty-eighth tier of townships. This cross section has the advantage of a record of a deep well at Nebraska City, one at Coin, one at College Springs, one at Clarinda, one at Bedford, and one at Leon. The outcrops near the line are few, the strata being concealed by drift excepting at scattered outcrops in some of the river valleys. To the north at some distance are the outcrops at Essex, Coburg, Hawleyville, Brooks, and Westerville; and to the south, outcrops at Hamburg, Coin, Braddyville, Davis City, and west of Lineville.

The record of the Nebraska City well may be found on page 1105 of volume XXI of the Iowa Geological Survey, and also on page 651 of volume XIX. While the interpretation offered there does not give the subdivisions of the Missouri series it is believed that with the assistance of the outcrops in the clay pit at Nebraska City and with the aid of the Nebraska section as drawn by Condra and Bengtson the horizons of the

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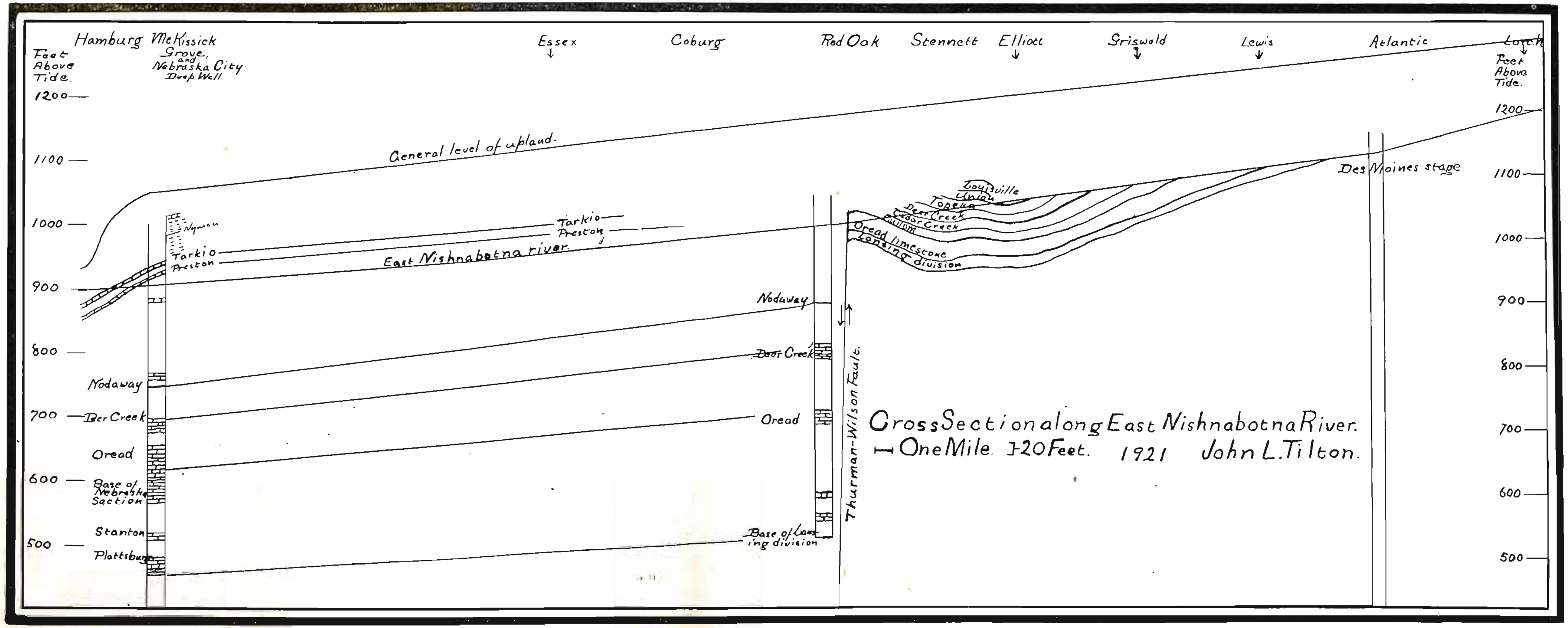
[57]John L. Tilton, The Strata near Stuart, Iowa: Bull. Geol. Soc. America, Vol XXXIII, p. 153, 1922.

[58]John L. Tilton, The Thurman-Wilson Fault through Southwestern Iowa, and its Bearing: Journal of Geology, Vol. XXVII, p. 387; and Geology of Adair County: Iowa Geol. Survey, Vol. XXVII, p. 304.



The cross section along East Nishnabotna river from Hamburg to Atlantic.

Tarkio, Deer Creek, and Oread limestones and the base of the section of Condra and Bengtson can be made out with considerable certainty; and possibly the base of the Hertha limestone may be determined, though with less of certainty. Between the base of the Condra and Bengtson section of the Pennsylvanian Formations of Southeastern Nebraska and the supposed base of the Hertha is a series of limestones and shales that are provisionally assigned names in accordance with their apparent relations. It is the judgment of Dr. George L. Smith that the well at Nebraska City is at the level of the Tarkio limestone, and that the shale dug for brick at the brickyard just south of the city is the McKissick Grove shale, the shale above the Tarkio limestone, and with this judgment the writer is in full accord. From this it is estimated that the Deer Creek is the limestone recorded at a depth of 250 feet, the Oread limestone is the one at 325 feet, the base of Condra and Bengtson's section is at 382 feet, and the base of the Hertha limestone (the base of the Missouri series) is at a depth of 702 feet. A condensed record locating the above named horizons is as follows:

	DEPTH	FEET ABOVE SEA LEVEL
Tarkio limestone		940
Top of well		930
Nodaway coal	215	715
Dear Creek limestone (Forbes)	250	680
Oread limestone (Plattsmouth)	325	605
Base of Condra and Bengtson section	382	548
Base of Hertha limestone	702	228
Top of Mississippian (Vol. XXI, I. G. S.)	1,020	—90
Top of Devonian (Vol. XXI, I. G. S.)	1,440	—510
Top of Ordovician (Vol. XXI, I. G. S.)	2,160	—1,230
Bottom of well (Vol. XXI, I. G. S.)	2,869	—1,939

Both Udden[59] and Smith[60] give detailed records of strata found at the high school at Hamburg:

	FEET	INCHES
4. Sandstone, coarse		3
3. Shale, divided in the middle by a hard band three inches thick	15	
2. Limestone, arenaceous		9
1. Shale	5	
	21	

59J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geol. Survey, Vol. XIII, p. 151.

60G. L. Smith, Carboniferous Section in Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 641.

The limestone in this section is 929 feet above sea level, or 16 feet above the Chicago, Burlington and Quincy railroad track at the station, and 29 feet above low water in Nishnabotna river. These strata Smith refers to the McKissick Grove shale, and he correlates the arenaceous limestone, No. 2, with the third layer from the top (No. 17) at McKissick grove, which stratum is characterized by spheroidal lumps about half an inch in diameter.

The McKissick grove series of outcrops extends east and west through section 13, Township 67 north, Range 42 west, two miles northeast of Hamburg. It is described by both Udden[61] and Smith.[62] Smith's description, with slight additional interpretation, is as follows:

		FEET	INCHES
19.	Shale, blue	12	
18.	Shale, gray, weathered	8	
17.	Limestone, very dark gray, arenaceous, many spheroidal lumps, in places brecciated	1	
16.	Limestone, blue, very arenaceous; might be termed a calcareous sandstone	1	
15.	Shale, arenaceous, micaceous	3	
14.	Sandstone, blue, weathering yellow	6	
13.	Shale, arenaceous, micaceous	2	6
12.	Sandstone, blue, weathering yellow	1	
11.	Shale, gray	9	
10.	Limestone, dark gray, in two layers; fossiliferous	3	
9.	Coal (Nyman)	1	
8.	Shale, yellow and blue	31	
	(McKissick Grove shale, thickness, 78 fet, 6 inches.)		
7.	Limestone, gray, fossiliferous		6
6.	Shale, dark gray	3	6
5.	Limestone, very dark gray	4	6
	(Tarkio limestone, thickness, 8 feet, 6 inches)		
4.	Shale, blue, weathering to yellow	8	
3.	Limestone, weathered brown; in two or three layers	4	
	(Preston limestone, 4 feet.)		
	(Total thickness of Wabaunsee stage, 99 feet,)		
2.	Shale, gray, weathered	12	
1.	Limestone, dark gray (Fargo)	1	
	(Scranton shale)		
		112	

The lowest stratum is close to the level of the railroad track, which is here seventeen feet above the level of the water in Nishnabotna river near by.

A record of the core drilling at Coin may be found in volume XIX of the Iowa Geological Survey, pages 630 to 633.

61Idem, pp. 151-154.

62G. L. Smith, Contributions to the Geology of Southwestern Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, p. 80; also Iowa Geol. Survey, Vol. XIX, p. 639.

The shale between the Deer Creek (Forbes) and the Oread (Plattsmouth) limestones here seems to be thickening toward the east. A condensed record is as follows:

	FEET DEPTH	FEET ABOVE SEA LEVEL
Top of well		1,039
Preston limestone	22	1,017
Nodaway coal	234	805
Bottom of Deer Creek limestone (Forbes)	287	752
Base of Oread limestone (Plattsmouth)	423	616
Bottom of well	450	589

The record of the diamond drill hole at Clarinda, given in volumes XII and XXI of the Iowa Geological Survey and interpreted and treated more at length by Smith in volume XIX, pages 618 to 620, is considered especially reliable. On comparison with the record at Coin a comparatively rapid rise of strata along the line chosen is noted, amounting to 164 feet in eight miles for the base of the Oread (Plattsmouth) limestone, and 149 feet for the horizon of the Nodaway coal, the eastern boundary of which is within two miles to the east of the well. A diminishing thickness of the Oread limestone is noted on comparison with the record at Nebraska City, provided the latter record does not include thin shaly beds with the limestone. A condensed record of the Clarinda hole is as follows:

	FEET DEPTH	FEET ABOVE SEA LEVEL
Top of well		1,005
Nodaway coal	55	950
Bottom of Deer Creek limestone (Forbes)	115	890
Base of Oread limestone (Plattsmouth)	241	764
Base of Plattsburg limestone	524	481
Base of Hertha limestone (base of Missouri series)	711	294
Bottom of well	840	165

The record, with interpretation by Smith, of the diamond drill hole at College Springs is given on pages 628 and 629 of volume XIX, Iowa Geological Survey. This well is located ten and one-half miles in a direction south twenty-five degrees west from the well at Clarinda. If the horizon of the Nodaway coal is placed on the line marking the position of the Nodaway coal as determined at Coin and at Clarinda the records of the Deer Creek and Oread limestone beds also fall into their respective places in the diagram. The well is so far to the south that a use of the record other than for confirmation seems impossible at present. The line on which the record is placed is also of value to determine the general level at which the Nodaway coal may be found should it be desirable to shaft for it. A condensed record of the well is as follows:

	FEET DEPTH
Nodaway coal	108
Bottom of Deer Creek limestone (Forbes)	163
Base of Oread limestone (Plattsmouth)	246½
Bottom of well	260

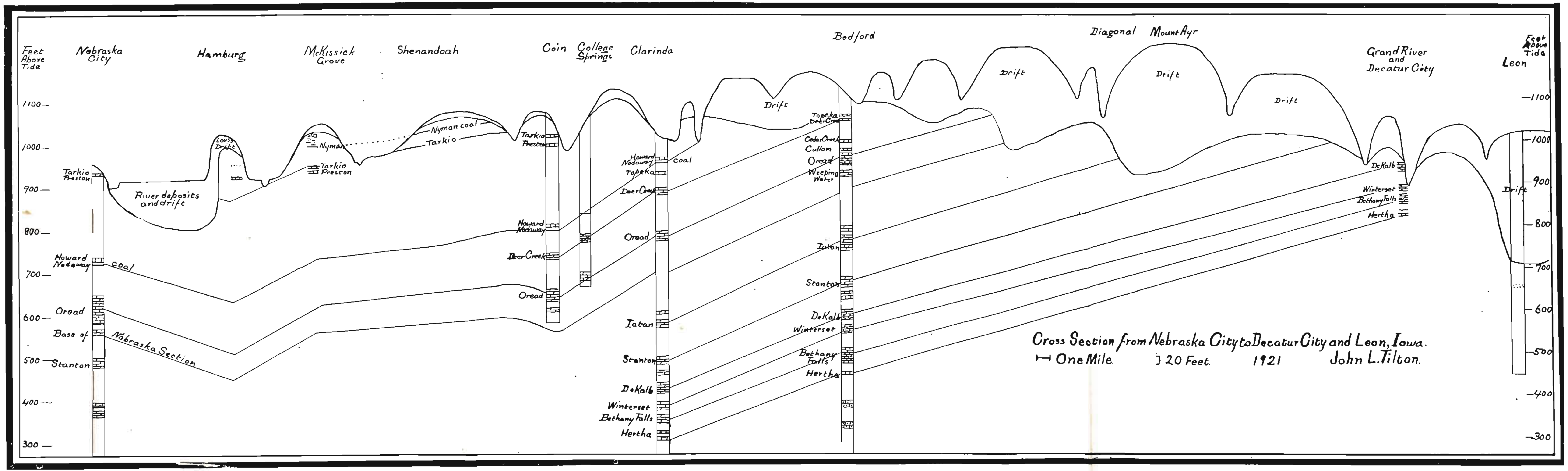
Doctor Smith reports that he finds the strata along Nodaway river south from Clarinda to have an average slope about equal to the slope of the river but in the opposite direction,[63] so that the Nodaway coal comes up to the river bank at Shambaugh. Seven miles northeast from Clarinda it appears again at Hawleyville. At both Hawleyville and Braddyville are small anticlines, with a syncline between, over which Clarinda is situated.

The record of the deep well at Bedford may be found in volume XXI of the Iowa Geological Survey, pages 1183 to 1185. Between Clarinda and Bedford, a distance of fifteen miles, the Deer Creek and Oread limestones each rise 168 feet, about half the rise per mile which is found between Coin and Clarinda. The limestone at a depth of 645 feet appears to be the Hertha limestone, at the base of the Missouri series (instead of the limestone at a depth of 760 feet, as given in the report). A condensed record of the well at Bedford is as follows:

	FEET DEPTH	FEET ABOVE SEA LEVEL
Top of well		1,098
Bottom of Deer Creek limestone (Forbes)	50	1,048
Bottom of Oread limestone (Plattsmouth)	150	948
Bottom of Stanton limestone	440	658
Bottom of Hertha limestone (base of Missouri series)	645	453
Bottom of well	2400	—1,302

Between the valley of the East Fork of One Hundred and Two river at Bedford and the valley of Grand river in Decatur county there are no exposures of stratified rock near the line of the cross section, and at present no records of deep wells, though it is reported wells have been put down through the

63G. L. Smith, Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 624, also Calvin, Geology of Page County: Iowa Geol. Survey, Vol. XI, p. 427.



Cross section from Nebraska City, Nebraska, to Decatur City and Leon, Iowa.

glacial drift. Somewhere beneath the thick drift of this region the Oread, Iatan and Stanton limestones come to the preglacial surface. Records in western Madison county and eastern Adair indicate that this portion of the Missouri series is thinner and less calcareous toward the east. Apparently the Oread limestone is nearest the surface near Clearfield, and the Iatan limestone is nearest the surface near Diagonal, where some evidence of its presence may be found along the valley of the West Fork of Grand river in Ringgold county. Apparently the few small exposures in sections 23 and 24, Lots Creek township, Ringgold county, are of Stanton limestone. A preglacial valley three hundred feet deep is reported in a well record at Mount Ayr, a location which corresponds to that of a preglacial valley eroded in the Vilas shale. The presence of such a valley is the occasion for the representation of another parallel valley seven miles west of Diagonal, where the Lawrence shale was subject to preglacial erosion. Eastward, at the end of the cross section, the record of the deep well or prospect hole at Leon locates another preglacial valley where the drift is three hundred and five feet deep.[64]

The cross section really ends at the bridge across Grand river three and one-half miles west of Decatur City in Decatur county, but the drawing is extended to include the evidence of a preglacial valley given in the record of the deep well at Leon, east of the area of the Missouri series. The top of the Winterset limestone at the bridge west of Decatur City is taken as being the stratum which is six feet above the level of low water in Grand river (890 feet above sea level), and the other strata of the Kansas City stage of the Missouri series, all of which up to and including the De Kalb limestone are found along the river within the county, are represented in their proper positions.

The Cross Section along Grand River, with Extension to Middle River.

The cross section along Grand river extends twenty-eight and three-fourths miles from Davis City, Decatur county, past

64In this connection one should not overlook Keyes's description of the Cap-au-Gres fault: Proc. Iowa Acad. Sci., Vol. XXIII, p. 104. No evidence of the extension of it through the area here studied has been found. An anticline is mentioned in the discussion of structure.

the town of Grand River, to Afton Junction, Union county, which three points afford opportunity to determine the level of the river bed above sea level.

	FEET
At Davis City:	
Level of the Chicago, Burlington and Quincy railroad station, Gannett's Dictionary of Levels, above sea level	914
Bed of river below railroad station, by barometer	32
Level of the river at Davis City, above sea level	882
Bridge at the town of Grand River, above sea level	971.4
Height of bridge above water	40
Level of the river at Grand River, above sea level	931.4
Afton Junction, level above sea level of the Chicago, Burlington and Quincy railroad station, Gannett's Dictionary of Levels	1,099
Bed of river beneath track, by barometer	60
Level of river at Afton Junction, above sea level	1,039

In this distance the total fall of the river is 157 feet, or 5.46 feet per mile, the gradient of the stream being uniform except for the effect of bends in the course of the stream, of a small dam about four feet high at Westerville, and of a similar one at Davis City. The general direction of the stream approximately parallels the eastern margin of the Missouri series in this part of the state, in which there is a rise in strata toward the northeast of about twenty-five feet in Decatur county and of one hundred and sixty feet from Davis City to Winterset. The cross section along Grand river may be extended northward to join the cross section along Middle river at Brushy branch between Madison and Adair counties, beyond which to the north the cross section along Middle river approximately parallels the eastern margin of the Missouri series.

At Davis City the base of the Bethany Falls limestone is about ten feet above the river, or 872 feet above sea level. This is taken as the starting point of the cross section. There is a part of each formation exposed within two miles southwest from Davis City, but not sufficient to make a complete composite section:

	FEET
4. Limestone (Winterset), exposed only	1½
3. Shale, gray (Galesburg), exposed only	4-5
2. Limestone (Bethany Falls), exposed only	8-10
1. Shale (Ladore), exposed to river bed	10

Five miles up the river from Davis City there is the crest of a small anticline, as described by Bain in his report on Decatur county (Vol. VIII, Iowa Geological Survey) that seems to line up with the anticline at the bridge three and one-half miles west of Decatur City, where a dip of 9° 35′ is to be found in the Winterset limestone. The overlying De Kalb limestone near by dips 3° 10′ in a direction S. 73° W. (In the chapter on Structure may be found a discussion of the relation of an unconformity here to a disconformity in the northern and western portions of the area under consideration). There are minor variations, but in general the rise of the strata in the direction of the cross section is uniform.

The section at Decatur bridge as described by Bain[65] is as follows:

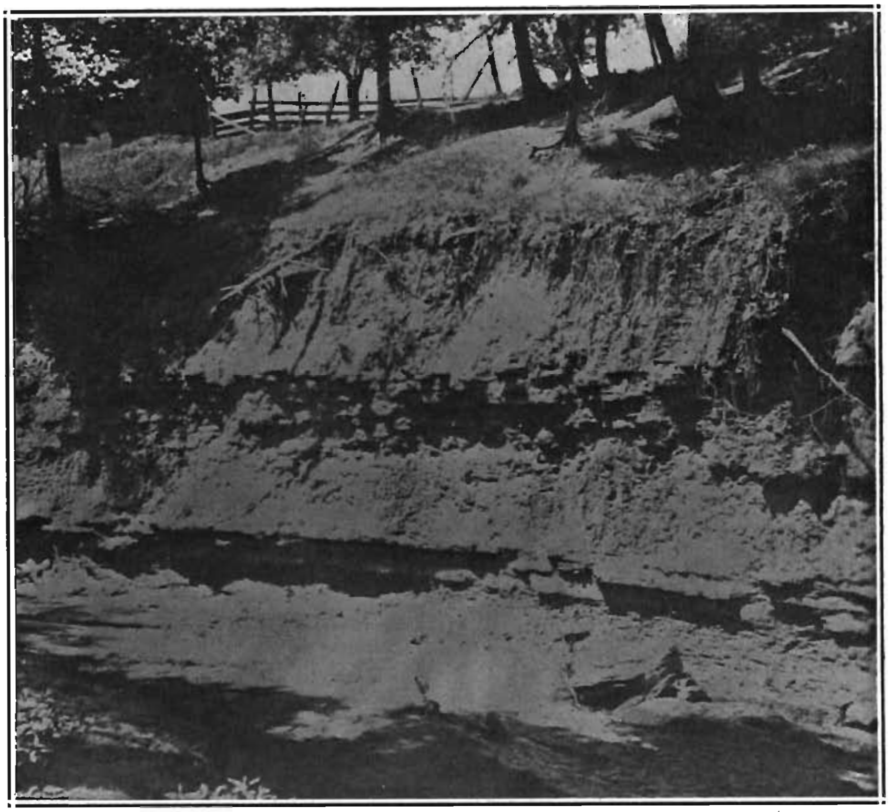


FIG. 38.—The base of the DeKalb limestone above the Cherryvale shale in a side ravine near the mouth of Sandy creek, Westerville. The Westerville limestone is weathered away from just above the face of the cliff but appears on the hillside close by. (Township 70 North, Range XXVII West, Southeast quarter of the Southwest quarter of section 21.)

65H. F. Bain, Geology of Decatur County: Iowa Geol. Survey, Vol. VIII, pp. 278-279.

		FEET
5.	Limestone, lower ledges only (De Kalb limestone)	3
4.	Shale, drab to black; *Chonetes verneuilianus, Composita subtilita, Orthotetes crassus, Productus nebrascensis, Myalina subquadrata, Rhombopora lepidodendroides, Lophophyllum proliferum* and *Eupachycrinus verucosus* (plates). There are thin ledges of limestone made up of *Chonetes verneuilianus*	15
3.	Limestone, blue to black; *Composita subtilita, Productus cora, P. nebrascensis*	3
2.	Shale, drab, clayey (Cherryvale shale, thickness, 30 feet.)	12
1.	Limestone, coarse bedded; *Composita subtilita, Productus costatus, Meekella striatocostata* (Winterset limestone). To bed of river	10
		43

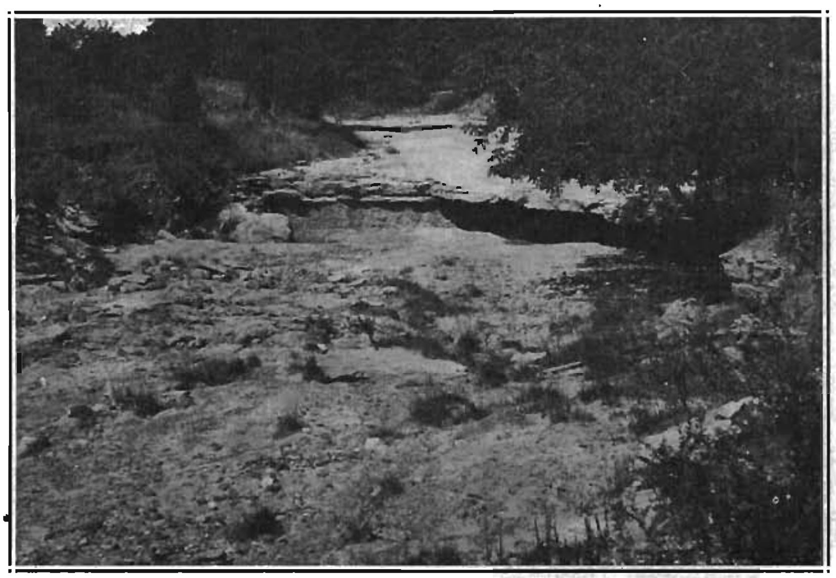


FIG. 39.—The top of the DeKalb limestone (Westerville) in the bed of Sandy creek near Westerville, Decatur county. (Township 70 north, Range XXVII west, east center of section 20.)

The full section as above described is not now visible, as the filling in around the west end of the bridge has concealed a portion of the upper shale.

Upstream from the section at the bridge west of Decatur City the next section used is obtained by combining the outcrop at Westerville with those a short distance up Sandy creek, where Bain's Westerville limestone is exposed in the bed of the creek, from the center of section 21 to the center of section 20, Township 70 north, Range XXVII west. The section is as follows:

		FEET	INCHES
9.	Limestone, dark gray; *Fusulina cylindrica*, spines of echinoids, *Naticopsis, Euomphalus*	6	
	(DeKalb limestone)		
8.	Shale, gray, nonfossiliferous	8	
7.	Shale and limestone alternating, *Meekella striatocostata* zone in center; *Productus nebrascensis*	3	8
6.	Shale, dark blue, nonfossiliferous, carbonaceous	3	
5.	Limestone, in three or four divisions, irregular shaly partings, very fossiliferous; *Chonetes verneuilianus, Composita subtilita, Productus nebrascensis, P. cora, Spirifer cameratus, Fenestella,* crinoid stems	1	9
4.	Shale, dark blue, nonfossiliferous	2	2
3.	Limestone, blue, upper half more compact than the lower half, which is in two parts	2	8
2.	Shale, blue, clayey	5	6
1.	Not fully exposed to river at low water, but about a foot is limestone at river	1	6
	(Cherryvale shale, thickness, 28 feet, 3 inches)		
		34	3

The above correlation, which is contrary to that of Bain,[66] is discussed under the head of Nomenclature.

The topmost limestone in the above section (Bain's Westerville) also outcrops at the level of Grand river at a ford (section 36) and at a bridge over Grand river directly west from Hopeville in the south center of section 11, both in Pleasant township, in the southeastern part of Union county[67]; and from two to three miles in a straight line northwest from the bridge mentioned may be found other sets of beds of limestone: sections 34, 33 and 28 of Jones township (Township 72 north, Range XXVIII west). A section in the southeast quarter of the northeast quarter of section 33 is as follows:

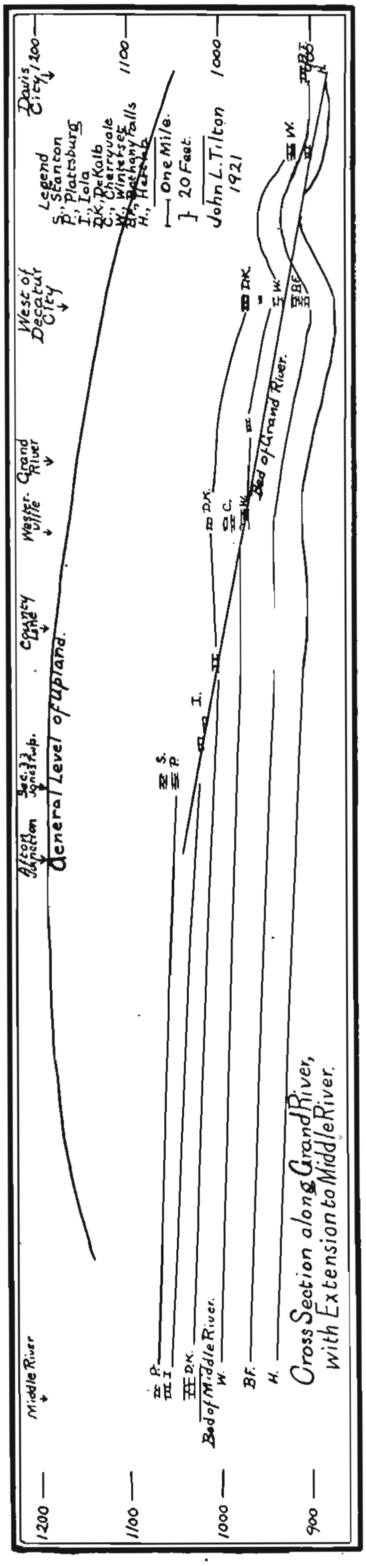
		FEET	INCHES
9.	Limestone, grayish brown, in beds from three to seven inches in thickness	8	6
	(Stanton limestone)		
8.	Not exposed	1	7
7.	Limestone, 3½ inches		
6.	Shale, 1 inch		
5.	Limestone, 3 inches		
4.	Shale, 6 inches		
3.	Limestone, 5 inches	1	6½
	(Plattsburg limestone)		
2.	Shale, greenish	1	6
	(Lane shale.)		
1.	Not exposed, to river at low water	26	6
		39	7

66H. F. Bain, Geology of Decatur County: Iowa Geol. Survey, Vol. VIII, pp. 276-278.

67John L. Tilton, Geology of Clarke County: Iowa Geol. Survey, Vol. XXVII, pp. 132-134.

Plate XXIV

Iowa Geological Survey



The cross section along Grand river from Middle river to Davis City.

The cross section along Grand river as drawn in beneath the river at Afton Junction may be connected with the cross section along Middle river by means of the section along Brushy branch close to the west line of Madison county. The only exposure of stratified rock from Afton Junction to the beds exposed along Middle river is one four miles north of Macksburg and only a mile and a half from Middle river. It is in the northeast quarter of the northeast quarter of section 27 and the southeast quarter of the southeast quarter of section 22 of Township 75 north, Range XXVIII west, where the De Kalb limestone appears near the bed of the creek. In a direct line between Afton Junction and Brushy branch all the rock is deeply concealed beneath drift, and there are no records of deep wells.

The Cross Section along Middle River.

The cross section along Middle river extends twenty-eight miles from Winterset, Madison county, to the southwest quarter of the southwest quarter of section 16, Jefferson township, Adair county, not far from Stuart. From Winterset for a distance of eight and one-half miles the various outcrops are referred to river level at right angles to a line extending N. 75° E., which is the general direction in which the river flows in that part of its course. Above this point (southwest quarter of the southwest quarter of section 14, Webster township) the general direction of the river is S. 38° E., to which direction the various outcrops are referred.

South of Winterset the elevation of the river above sea level is 927 feet. At section 16, Jefferson township, Adair county, the elevation is 1135 feet, giving a total fall of 208 feet, an average of 7.43 feet per mile. From a point five miles west of Winterset to a point seven miles still farther west along the line representing the general course of the stream the regularity of the slope is interfered with by limestone fragments that have accumulated at the mouths of ravines, causing the river at low water to change in level by successive steps from one pool of quiet water to the next, between which are stretches of rapid water. The regularity of slope along the general direction of flow is also interfered with by the presence of numerous large bends, some of which are distinctly meanders. To some extent, at least, these successive steps in this part of the course tend to change the general shape of a stream (concave upward) into a slope that is more nearly that of a straight line than would be the case if the small rapids did not exist. There has been a small dam at Port Union mill, but what there is left of it offers little obstruction to the stream at low water. Between the two extremes there is no chance to ascertain the amount of departure of the gradient of the stream from the average, except by repeated trips with barometer.

A more serious difficulty than that due to deposits of fragments of limestone, which tend to improve the general gradient, and that due to large bends, which partly equalize themselves, is one dependent on the dip of the strata, for which allowance should be made in examining the cross section. The general dip is toward the southwest, at an angle with the course of the river. When records from ravines on the south side of the river are placed near records made on the north side of the river, followed again by a record from the south side of the river, and all referred to the level of the stream, the result in a drawing resembles an anticline, magnified, of course, by the scales used. Records taken first north, then south, then north again, make a drawing resemble a syncline. The same principle applies when measurements near the river are compared with measurements taken at some distance from the river. Such results may be found in the cross section at points ten miles and fourteen miles west of Winterset. Such a representation is deceptive; yet, since correlation rather than structure is here desired, it is thought better to place the individual sections just as they were measured than to attempt to allow for the effect of the dip. There is a slight anticline where the diagram represents one, but not nearly of the magnitude the diagram represents. In the entire region the dip is slight. Measurements are given in the discussion of structure.

The cross section along Middle river is of peculiar value. It gives the relation of the strata from the Hertha at the base of the Kansas City stage near Winterset to the highest strata of the Missouri series found east of the state divide. From its northwest end there are but seven miles across the drift in the region of the Thurman-Wilson fault to the shales and limestones three miles north of Stuart, long mapped as of Missouri age but in reality belonging far down in the Des Moines series.

The Middle river section approaches the section along Nishnabotna river and reveals in Harrison township, Adair county, the thin Oread beds that appear at Riverview park near Red Oak, Montgomery county, and also on Turkey creek at a point two miles northeast of Lewis, Cass county. Above the Oread in Adair county are other limestones (Deer Creek) that assist somewhat in the correlation with beds near Stennett, Montgomery county. The Middle river section, near the west Madison county line, also approaches the Grand river section from Davis City to Afton Junction.

The region around Winterset is historical geologically. Here White spent a couple of weeks in study of local conditions preparatory to the publication of his report on the region.[68] Here Calvin worked in his extensive studies, and here Bain and Tilton accumulated data for the report on Madison county, to be

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[68]Charles A. White, Report on the Geological Survey of Iowa: Vol. 1, pp. 241-250 and 305-309.

found in volume VII of the present series. This location is chosen for the first portion of the section along the river, though the Hertha may be found farther east even to St. Charles. Where the road southwest from Winterset turns up the river valley (southeast quarter of the northwest quarter of section 12) the Pleasanton sandstone with Hertha above it may be seen by the roadside. Along the ravine southeast from Winterset there is a complete section from the uppermost portion of the Hertha to the top of the Cherryvale shale. Fragments of De Kalb limestone are to be seen but no beds in place.

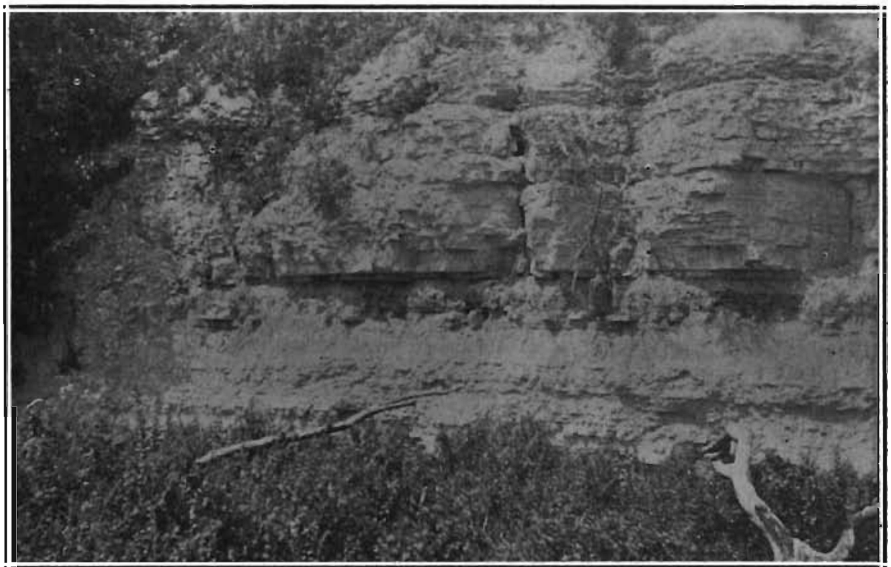


FIG. 40.—The Bethany Falls (Earlham) limestone in a ravine southwest of Winterset, Madison county.

It is here that the following described section was measured:

THE SECTION AT WINTERSET

	FEET	INCHES
26. Drift to upland at (old) railroad station, 1,118 feet above sea level	31	2
25. Shale, gray, argillaceous; apparently beneath limestone		
24. Limestone, blue, in three layers with partings of shale, the so-called *Myalina* horizon in the Cherryvale shale, very fossiliferous: *Myalina swallovi*, *Orthotetes* (*Derbya*) *crassus*, *Chonetes verneuilianus*		
23. Shale, gray, argillaceous, with bed of *Chonetes verneuilianus* in upper portion	16	
(Cherryvale shale, thickness, 16 feet.)		

		Feet	Inches
22.	Limestone, gray, fragmental in upper portion	5	2
21.	Limestone, gray, very resistant ledge; with chert	2	3
20.	Limestone, gray	1	2
19.	Shale, gray, argillaceous; *Composita subtilita*		3
18.	Limestone, gray	1	9
17.	Limestone, gray; partings of shale	3	3
	(Winterset limestone, thickness, 13 feet, 10 inches.)		
16.	Shale, gray, argillaceous	1	6
15.	Shale, black	1	6
14.	Shale, gray, argillaceous above, calcareous below	7	
	(Galesburg shale, thickness, 10 feet.)		
13.	Limestone, gray, in beds from 1 foot to 1 foot, 6 inches thick, top portion fragmental; many fragments of crinoid stems, *Chonetes verneuilianus*, *Composita subtilita* and occasional *Phillipsia*	20	
	(Bethany Falls limestone, thickness, 20 feet.)		
12.	Shale, gray, argillaceous	2	10
11.	Shale, black (seam of coal elsewhere)	1	2
10.	Limestone, dark blue		8
9.	Shale, calcareous in places	1	10
8.	Limestone, gray	1	5
7.	Shale, gray, argillaceous	4	9
6.	Limestone, gray	1	10
5.	Shale, gray, argillaceous	6	6
	(Ladore shale, thickness, 21 feet.)		
4.	Limestone, gray; *Composita subtilita*	2	8
3.	Shale, gray, argillaceous	8	10
2.	Limestone, gray, very fragmental	6	
	(Hertha limestone, thickness, 16 feet, 6 inches)		
1.	Not exposed, to river bed (but Pleasanton shale appears elsewhere)	66	6
		164	10

At a number of places between Winterset and the "Backbone" limestone and shale are visible from the road along the river. The next section used is along a ravine through sections 27 and 22 of Lincoln township.

		Feet	Inches
15.	Drift to the level of the upland, as at Winterset		
14.	Limestone, gray; many *Fusulina*, *Spirifer camerata*, *Syringopora*	4	3
13.	Shale, gray above; lowest 14 inches is blue	3	
12.	Limestone, gray	1	6
11.	Shale, gray above, black below; contains ½-inch coal	4	
10.	Limestone, gray	2	
9.	Shale, gray, argillaceous	1	
8.	Limestone, gray	1	
	(De Kalb limestone, thickness, 16 feet, 9 inches.)		
7.	Shale (Cherryvale), with blue limestone as at Winterset; horizon of *Chonetes verneuilianus* in shale below the blue limestone; blue limestone above marking horizon of *Myalina swallovi* and *Productus cora*	10	

		FEET	INCHES
6.	Limestone (Winterset), thin layers above, thicker layers below, with shaly partings	14	
5.	Shale (Galesburg), black shale between two gray shales	10	7
4.	Limestone (Bethany Falls), gray, in layers of various thicknesses up to a foot or so; top very fragmental	20	
3.	Shale (Ladore,) with included limestone	18	
2.	Limestone (Hertha,) with included shale	14	
1.	Not exposed, from base of Hertha to Middle river	13	
		116	4

At the tunnel a mile up the river, where a mill was once located, the base of the Hertha is close to the level of the river[68a]; and across the river to the north may be found a duplicate of

FIG. 41.—The Winterset limestone close to Winterset, Madison county, along road south from Winterset.

68aThis location is now chosen for a state park.

the section above described, with parts of it even better exposed than in the section here given.

Between the section above described and the next one, situated two miles west and two north, the river flows several miles, perhaps eight, causing the river to appear to rise more rapidly into the sections of strata than it appears to rise farther east; but this is characteristic of conditions for four miles farther west. A good series of exposures may be found along a ra-

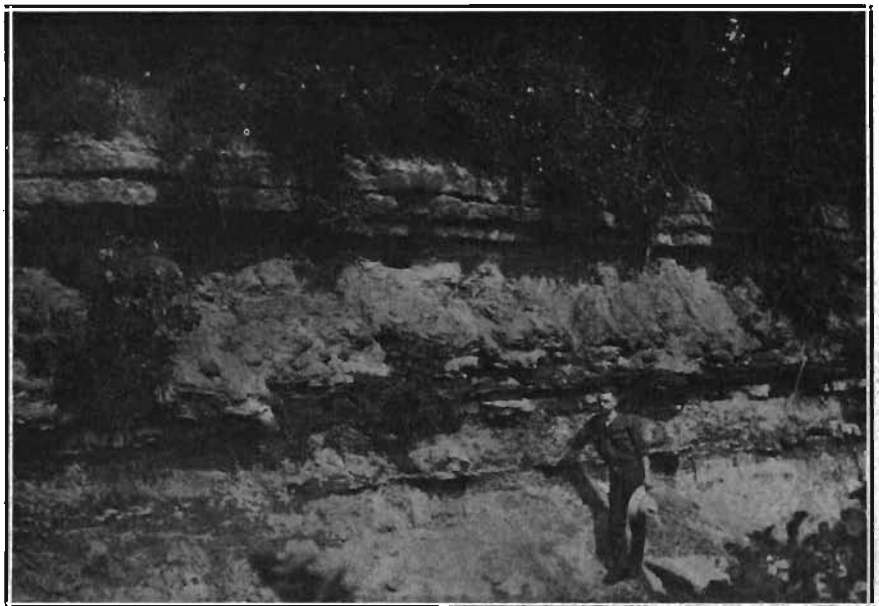


FIG. 42.—The Cherryvale shale in a ravine on north side of Middle river five miles west of Winterset, Madison county. The DeKalb limestone appears above the Cherryvale shale. (Township 75 north, Range XXVIII west; southwest quarter of the southwest quarter of section 8.)

vine in section 17 and another along a ravine in section 8 of Lincoln township, the latter of which is here described:

		FEET	INCHES
21.	From top of limestone to level of low upland an eighth of a mile to the east	50	
20.	Limestone, gray, in thin layers; crinoid stems (De Kalb limestone, thickness, 6 feet.)	6	
19.	Shale, gray, argillaceous	2	
18.	Limestone, gray	2	
17.	Shale, gray, argillaceous	5	
16.	Limestone, nodular		4
15.	Shale, black	1	3
14.	Limestone, black, in one stratum; *Orthotetes (Derbya) crassus, Productus cora, P. nebrascensis*		5
13.	Shale, blue above, gray below; one foot below the		

		Feet	Inches
	top is a bed of *Chonetes verneuilianus;* a foot below this bed is a bed of *Orthotetes* (*Derbya*) *crassus*	6	
12.	Concealed, but undoubtedly shale	3	
	(Cherryvale shale, thickness, 20 feet.)		
11.	Limestone, gray	1	
10.	Limestone, gray, in thin layers	6	
9.	Shale, gray	2	4
8.	Shale, black		8
7.	Limestone	1	6
	(Winterset, thickness, 11 feet, 6 inches.)		
6.	Not exposed (Galesburg shale)	13	
5.	Limestone, gray	2	6
4.	Limestone, gray, in various thicknesses, including a brownish shaly parting; with a 1 foot, 3 inch bed beneath the thinner beds, and a 6 inch bed at base	32	
	(Bethany Falls limestone, thickness, 34 feet, 6 inches.)		
3.	Shale, black	3	
2.	Not exposed	5	
1.	Shale, calcareous; to river bed	3	8
	(Ladore shale, thickness here exposed, 11 feet, 8 inches.)		
		96	8

There is a short series of exposures along a ravine in the extreme southeast corner of section 12, Webster township, about half way between the series just described and the one extending diagonally through section 13, Webster township. The latter is as follows:

		Feet	Inches
35.	Limestone, gray, slight exposure by roadside near the northeast corner of section 23, 67 feet above river	1	
34.	Not exposed	4	
33.	Limestone, gray, slight exposure in east-west road, near northwest corner of section 24, and west in ravine	1	6
32.	Not exposed	6	
31.	Limestone, weathered and broken	1	6
30.	Shale, blue, argillaceous		10
29.	Limestone, yellow		3
28.	Shale, yellow	1	
27.	Limestone, gray, with a two inch shaly parting; crinoid stems	2	
	(Apparently all of the above is in the De Kalb limestone, 18 feet.)		
26.	Shale, gray, calcareous in places	2	9
25.	Shale, carbonaceous	1	9
24.	Shale, dark, argillaceous		5
23.	Limestone, dark gray		7
22.	Shale, dark blue	1	8
21.	Limestone, blue; *Orthotetes* (*Derbya*) *crassus; Productus nebrascensis, P. cora,* very fossiliferous		5
20.	Shale, gray, with diagonal cross seams of shale;		

		Feet	Inches
	Orthotetes (*Derbya*) *crassus*	3	6
	(Cherryvale shale, thickness, 11 feet.)		
19.	Limestone, gray, in heavy ledge	1	5
18.	Limestone, in three parts	1	1
17.	Shale		4
16.	Limestone, gray		7
15.	Shale, parting in limestone		1
14.	Limestone, gray		5
13.	Shale, parting in limestone		3
12.	Limestone, gray, in two layers	1	3
11.	Shale, gray, calcareous, fossiliferous	1	2
10.	Shale, calcareous, weathered	2	7
	(Winterset limestone, thickness, 9 feet.)		
9.	Shale (Galesburg)	6	
8.	Limestone; *Fusulina*		6
7.	Not exposed	7	
6.	Shale, gray, argillaceous; *Chonetes verneuilianus*	2	
5.	Limestone, very dark gray; *Orthotetes* (*Derbya*) *crassus*		6.5
4.	Limestone, gray, concretionary		3
3.	Shale, gray, calcareous	2	2
2.	Limestone, light brown, weathered (exposed)		2
1.	Not exposed, to low water in Middle river	9	10
	(Bethany Falls limestone, thickness, about 22.5 feet.)		
		66	10.5

In the northeast quarter of the southeast quarter of section 14, Webster township, on both sides of the river, near the wooden bridge, the top of exposures of Winterset limestone appear twenty and one-half feet above low water in the river, and a portion of the Bethany Falls limestone is to be seen close to the river. The section here is as follows:

		Feet
5.	Limestone, gray; exposed (Winterset)	4
4.	Not exposed, (Galesburg shale)	8½
3.	Limestone, lower part with *Fusulina*	4
2.	Limestone, gray; large *Productus* shells	1
1.	Not exposed, to low water in Middle river	5
	(Bethany Falls limestone, thickness 10 feet)	
		22½

The Winterset limestone disappears beneath the river bed about a mile above this bridge. Ten or twelve feet of De Kalb limestone is to be found up Welly's branch (southwest quarter of the southeast quarter of section 14) about twenty feet above the Winterset limestone. The De Kalb limestone also appears in the roadway west in the center of section 14, and in a small ravine in the southwest quarter of the southwest quarter of section 14, where the series of exposures gives the following, including a nearly perfect section of the Cherryvale shale:

		FEET	INCHES
10.	Limestone, gray, in various thicknesses from two inches up to ten inches; light colored chert; very fossiliferous; crinoid stems, *Composita subtilita* (De Kalb limestone)	9	
9.	Shale, gray, argillaceous		10
8.	Limestone, light blue; crinoid stems, Pelecypods	2	
7.	Not exposed	3	
6.	Shale, black	1	
5.	Limestone, blue; *Productus prattenianus*		5
4.	Shale, gray, argillaceous; *Orthotetes* (*Derbya*) *crassus* zone	2	5
3.	Shale, gray, argillaceous	1	10
	(Cherryvale shale, thickness, 11½ feet.)		
2.	Limestone (top of Winterset), shaly	3	
1.	Not exposed, to low water in Middle river	4	
		27	6

In the northwest quarter of the northwest quarter of this same section ten feet of De Kalb limestone appears up a ravine, the base of the limestone being thirty-nine feet above low water in the river. In section 10 (southeast quarter of the southwest quarter) the base of this limestone by the roadside and in a field is nine feet above the river. In section 15 to the south (southeast quarter of the northwest quarter) the base of this limestone is three and one-half feet above the river at a place where the series of exposures gives the following:

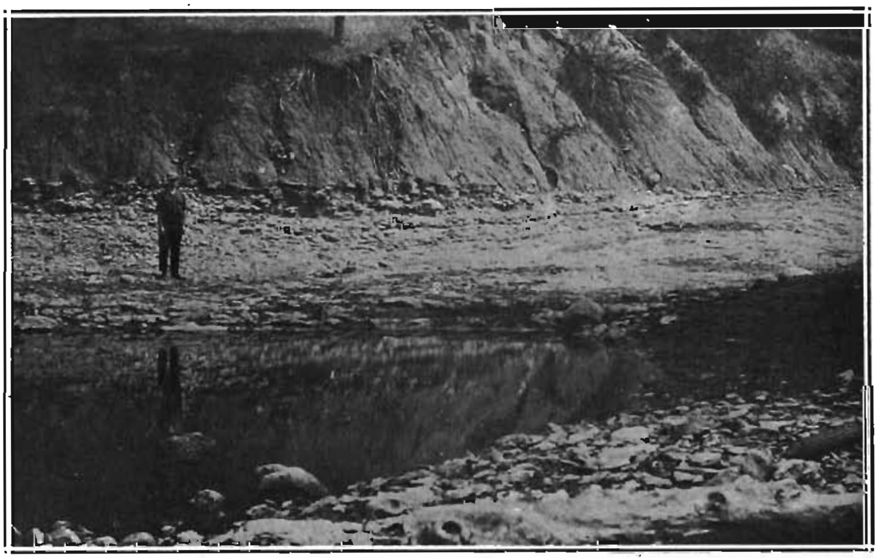


FIG. 43.—All that is left of the DeKalb limestone in the ravine northwest of Osceola. (Township 72 north, Range XXVI west, southeast quarter of the southeast quarter of section 11.)

		FEET	INCHES
14.	Limestone, thin layers, weathered	1	
13.	Limestone, dense, gray, light colored chert in places	1	10
12.	Shale, upper part gray, lower part black		4
11.	Limestone, gray, concretionary		1.5
10.	Shale, light blue, with *Chonetes verneuilianus* bed nine inches from base	2	
9.	Calcareous, nodular layer		2.5
8.	Shale, gray, argillaceous	3	11
	(Chanute shale, thickness, 9 feet, 5 inches.)		
7.	Limestone, light colored, with shaly partings	1	
6.	Limestone, gray, shaly	5	
5.	Limestone, gray, in thick bed	2	
4.	Shale, gray, argillaceous		10
3.	Limestone, gray, various thicknesses up to 2 feet, 5 inches	10	
	(De Kalb limestone, thickness, 22 feet, 3 inches.)		
2.	Shale, gray and blue	2	5
1.	Shale, black, to level of low water in Middle river	1	
	(Cherryvale shale, thickness, 3.5 feet.)	—	—
		31	8

In section 9 (southeast quarter of the southeast quarter) the base of the De Kalb limestone is nine feet above the river. The section here is as follows:

		FEET	INCHES
7.	Limestone, gray, thin layers in upper portion, thick layers in lower portion (De Kalb limestone)	6	
6.	Shale, grayish brown above, dark below	2	8
5.	Shale, calcareous	1	9
4.	Shale, blue		3
3.	Limestone, blue		6
2.	Shale, blue; *Myalina swallovi, Productus nebrascensis, P. cora, Orthotetes (Derbya) crassus*	2	4
1.	Shale, light gray, to level of low water in Middle river	1	6
	(Cherryvale shale, exposed, 9 feet.)	—	—
		15	

In section 16 (northwest quarter of the northeast quarter) the base of the De Kalb limestone is close to the level of the water in the river. In section 9 (northwest quarter of the southeast quarter) this same limestone extends in a vertical cliff from beneath the water in the river to a height of fifteen feet above the water. In section 8 (northwest quarter of the southeast quarter) the De Kalb limestone makes a low escarpment about ten feet high along the side of the flood plain for a quarter of a mile. In section 5 (southwest quarter of the southeast quarter) as far as a mile east of Webster it is this same limestone that is in the escarpment; but the limestone rises from the south since black shale appears by the river at the west end of the bridge in the southcentral part of section 5. It also appears in the lower part of the Brushy branch series of outcrops in sections 8 and 7 of Webster township, where the series gives the following:

		FEET	INCHES
22.	Limestone, gray; echinoid spines, crinoid stems (better seen in ravine one-fourth mile west)	5	
	(Plattsburg limestone.)		
21.	Shale, green, clayey	2	6
20.	Limestone, greenish, lower half shaly	1	4
19.	Shale, greenish	1	6
18.	Limestone, dense, jointed; crinoid stems		7
17.	Shale, gray, arenaceous, micaceous and calcareous	1	
	(Lane shales, thickness, 6 feet, 11 inches.)		
16.	Limestone, very fossiliferous; coral, crinoid stems, Bryozoa, *Chonetes verneuilianus, Productus*		10
15.	Shale, gray above, dark below	1	4
14.	Limestone, somewhat fragmental		10
	(Iola limestone, thickness, 3 feet.)		
13.	Shale, drab	4	8
12.	Shale, red	4	3
11.	Shale, green, calcareous	1	
10.	Limestone, bluish, somewhat fragmental but dense; *Composita subtilita*	1	4
	(The above series is from the roadway and ravine in the northwest quarter of section 7; the portion below is taken along the creek to the east.)		
9.	Limestone, bluish gray	1	6
8.	Shale, gray, including five or six nodular calcareous layers; *Chonetes verneuilianus, Productus cora,* Bryozoa	4	6
	(Chanute shale, thickness, 17 feet, 3 inches.)		
7.	Limestone, the mass of which is made up of calcareous pebbles, some about half an inch in diameter, and *Fusulina;* slightly arenaceous in the upper portion	5	10
6.	Limestone, gray, in thin layers above, thick layers below; *Marginifera longispina, Composita subtilita,* crinoid stems, echinoid spines	8	
	(De Kalb limestone, 13 feet, 10 inches.)		
5.	Shale, gray, argillaceous	1	
4.	Limestone, gray		1
3.	Shale, gray, argillaceous	1	
2.	Limestone, gray, in four equal parts	2	
1.	Shale, blue, argillaceous, to low water in river	1	3
	(Cherryvale shale, exposed thickness, 5 feet, 4 inches.)		
		47	2

Beginning with the Iola limestone of the above series of sections and ending with the Lawrence shale the numerous limestones and shales are grouped somewhat arbitrarily and tentatively following the nomenclature of Hinds and Greene in their description of "The Stratigraphy of the Pennsylvanian Series in Missouri." The strata vary northward to such an extent that with present knowledge exact parallelism is impossible. The Oread limestone, following the Lawrence shale, has definite characteristics that can be used to correlate it with strata in Cass and Montgomery counties and with those (Plattsmouth) at the mouth of Platte river, Nebraska. For the strata above the Lawrence shale the Nebraska nomenclature is used.

In the next four miles above Brushy branch the strata meet the river at varied distances along extensive windings of the stream. They rise fairly uniformly to the northeast, while the river valley in its general direction cuts them diagonally from the northwest to the southeast.

FIG. 44.—Section near the mouth of a ravine in the northeast quarter of the northeast quarter of section 1 of Grand River township, Adair county. (Township 75 north, Range XXX west.) The man in the picture is standing at the level of the Iola limestone. The section is described in the text.

A mile to the north of Brushy branch in section 6 of Webster township (southeast quarter of the northwest quarter) the peculiar limestone made up of small calcareous pebbles about one-half inch in diameter and of *Fusulinas* (the upper part of the De Kalb limestone) is about twenty feet above the water in the river. In section 1 of Grand river township, Adair county (northeast quarter of the northeast quarter) the same peculiar limestone is judged to be about five feet below the lowest stratum exposed in the ravine. (See figure 44.) The entire series of strata is as follows:

		FEET	INCHES
16.	Fragments of limestone	2	
15.	Limestone, dense, gray	1	3
	(Plattsburg limestone, thickness, 3 feet, 3 inches.)		
14.	Shale, yellow	1	6
13.	Limestone, dark blue, brown at top	1	
12.	Shale, gray, argillaceous, lowest foot reddish	6	6
	(Lane shale, thickness, 9 feet.)		
11.	Limestone, concretionary	1	3
10.	Shale, greenish gray	2	8
	(Iola limestone, thickness, 3 feet, 11 inches.)		
9.	Shale, red	3	6
8.	Shale, gray, argillaceous, without fossils	16	5
7.	Limestone, weathered		4
6.	Shale, dark gray		7
5.	Limestone, dark gray		6
4.	Shale, dark	1	4
3.	Limestone, dark gray		10
2.	Shale, gray	9	5
1.	Not exposed, to low water in Middle river	9	
	(Chanute shale, thickness, 41 feet, 11 inches.)	—	—
		58	1

About a mile farther up the valley in section 36 of Harrison township, Adair county (southeast quarter of the southwest quarter) a ravine side reveals the following:

		FEET	INCHES
14.	Limestone, weathered, and shale; *Chonetes striatocostatus* (abundant), *Orthotetes* (*Derbya*) *crassus*, *Composita subtilita*, *Productus nebrascensis*, *P. cora*, coral, crinoid stems	3	
13.	Limestone, blue above, gray below; *Chonetes striatocostatus*, *Productus nebrascensis*, *Fusulina cylindrica*	2	6
	(Plattsburg limestone, thickness, 5 feet, 6 inches.)		
12.	Not exposed (Lane shale)	2	6
11.	Limestone, dark gray; crinoid stems	1	3
10.	Shale		5
9.	Limestone, blue, very fossiliferous, chiefly *Orthotetes* (*Derbya*) *crassus*, bryozoa		5
	(Iola limestone, thickness, 2 feet, 1 inch.)		
8.	Shale, gray, argillaceous, without fossils	5	
7.	Shale, red		8
6.	Shale, argillaceous and calcareous	1	6
5.	Shale, gray	1	8
4.	Shale, red	2	10
3.	Shale, dark	3	
2.	Shale, gray	5	
1.	Not exposed, to low water in Middle river	16	
	(Chanute shale, thickness, 18 + feet.)	—	—
		45	9

The three lowest strata in the description preceding the above are here below the bed of the ravine.

An excellent series of outcrops appears by the road within another mile to the northwest, in section 35, Harrison township (northwest quarter of the northwest quarter) and may be described as follows:

		Feet	Inches
14.	Limestone, in thin layers	1	8
13.	Limestone, consisting of millions of *Fusulina* closely packed together, lowest two feet shaly or fragmental; *Fusulina cylindrica*, *Chonetes granulifer*, *Spirifer cameratus*, coral	3	10
	(Oread [Plattsmouth] limestone, thickness, 5 feet, 6 inches.)		
12.	Shale, gray; crinoid stems, *Productus nebrascensis*, zones of *Chonetes granulifer* (Lawrence shale)	6	8
11.	Limestone, dark gray; *Chonetes granulifer*, *Productus cora*, crinoid stems		7
10.	Shale, calcareous; crinoid stems		8
9.	Limestone, gray and dark, somewhat weathered brown, layers three inches to six inches thick; *Productus cora*, crinoid stems	3	3
	(Iatan limestone, thickness, 4 feet, 6 inches.)		
8.	Shale, gray, without fossils	2	
7.	Shale, black, without fossils	1	2
6.	Shale, gray, without fossils		10
	(Weston shale, thickness, 4 feet.)		
5.	Limestone, gray, dense; crinoid stems, *Productus cora*	1	2
4.	Shale, blue, without fossils	1	
3.	Limestone, dark gray		6
	(Stanton limestone, thickness, 3 feet, 8 inches.)		
2.	Shale, without fossils	1	
1.	Not exposed, to level of water in Middle river (but probably shale)	15	
	(Vilas shale.)		
		39	4

The lowest limestone (Stanton) above mentioned is the first limestone above the strata of the preceding section.

The next described series of outcrops is on the opposite side of a hill and about half a mile distant, along a ravine in section 27 (southeast quarter of the southeast quarter), Harrison township, Adair county. The series is described as follows:

		Feet	Inches
19.	Shale, beneath red residual material (geest)	4	
18.	Limestone. Lecompton (Cedar Creek), gray, fragmental in upper part, channelled by underground solution; *Fusulina*, crinoid stems		11
17.	Shale, light colored, calcareous	5	
16.	Limestone, Lecompton (Cullom), with shaly partings, fragmental at top, gray and arenaceous; bottom part very fossiliferous; fragments, fish tooth, bryozoa, *Dielasma bovidens*	1	10

		FEET	INCHES
15.	Shale, upper three feet and eight inches gray, calcareous, central three feet red, bottom four feet gray; without fossils	10	8
14.	Limestone, Oread (Plattsmouth), fragmental; *Fusulina*, *Productus cora*	7	7
13.	Shale, Lawrence, gray, calcareous; *Productus cora*, *Spirifer cameratus*, *Chonetes*, crinoid stems, coral	5	7
12.	Limestone, Iatan, dark, shaly; *Productus nebrascensis*, *P. cora*	3	8
11.	Shale, gray		2
10.	Limestone, dark; *Productus nebrascensis*		5
9.	Shale, gray; *Productus nebrascensis*		2
8.	Limestone, dark		4
7.	Shale, gray		1.5
	(Weston shale, thickness, 1 foot, 3.5 inches.)		
6.	Limestone, dark, irregular; *Productus nebrascensis*, *Spirifer cameratus*		3
5.	Shale, dark gray, argillaceous, without fossils		3
4.	Limestone, bluish gray, in thin layers one inch to three inches thick; algalike markings, crinoid stems (margins rounded), *Productus cora*	1	2
3.	Limestone, gray, dense, algalike markings, iron concretions	1	5
	(Stanton limestone, thickness, 3 feet, 1 inch.)		
2.	Shale, Vilas, argillaceous, gray and green, iron concretions	1	9
1.	Not exposed, to level of low water in Middle river	4	
		49	3.5

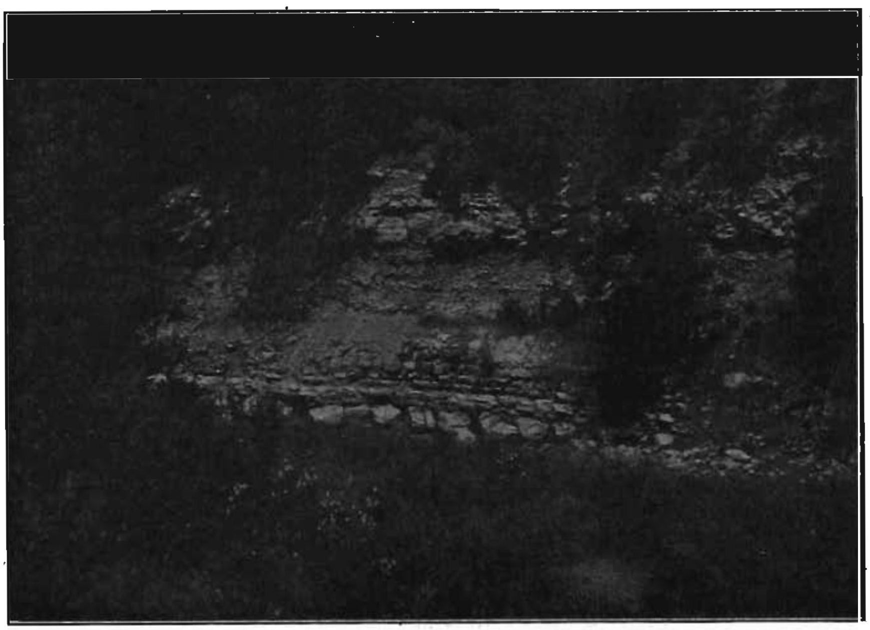


FIG. 45.—Section in a ravine in the southeast quarter of the southeast quarter of section 27, Harrison township, Adair county. (Township 76 north, Range XXX west.) The Stanton limestone is at the base of the cliff, the Iatan limestone near the center, and the Oread limestone near the top. All of the strata appear in the bed and sides of the trench farther up the ravine to the west. The section is described in the text.

FIG. 46.—"Port Union Mill" in half a mile upstream from the bridge at Arbor Hill. It is located in the southwest quarter of the northeast quarter of section 20, Township 76 north, Range XXX west. The base of the Deer Creek (Forbes) limestone is the ledge over which the water flows just below the dam. The section is described in the text.

The top of the Lawrence shale appears in a ravine by the road nearly a mile north (section 27, northeast quarter of the northeast quarter); and at the bridge (section 22, southeast quarter of the southeast quarter) the Oread limestone is four feet thick and is eight feet above the river. In section 21 (southeast quarter of the southeast quarter) the Oread apparently is below the river bed. About a foot of poor limestone is here exposed four feet above the river, with four to five feet

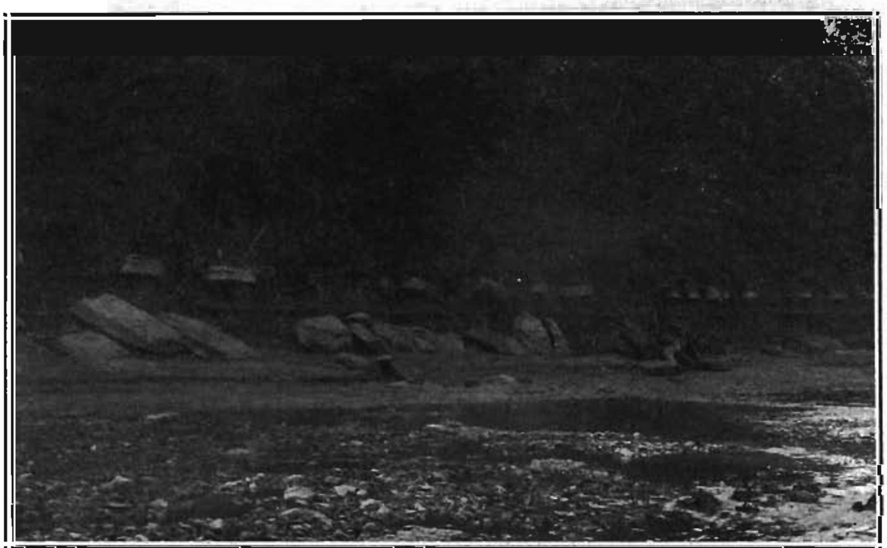


FIG. 47.—The location is a few rods down stream from the dam at "Port Union Mill," looking westward at beds associated with the Deer Creek (Forbes) limestone.

FIG. 48.—The Deer Creek (Forbes) limestone found at "Port Union Mill" and near Stennett also outcrops north of Hawleyville in Page county (Township 69 north, Range XXXVI west, northeast quarter of section 12). This outcrop was illustrated and described in the report on the "Geology of Page County." The limestone that is uppermost is the Topeka (Meadow) limestone.

of reddish and greenish shale above the limestone. In section 21 (northeast quarter of the southwest quarter) a limestone is three feet above water in the river; at Arbor Hill bridge (section 20, southeast quarter of the northeast quarter) this particular limestone is at the level of the water under the bridge. Half a mile up stream from the bridge is the site of the "Port Union mill," at which place James E. Gow described a section as follows (southwest quarter of the northeast quarter of section 20:

	FEET
3. Limestone, light buff, varying to white or light gray; *Composita subtilita, Orthotetes (Derbya) crassus, Spirifer cameratus, Productus* fragments, *Myalina subquadrata*, crinoid stems, *Fenestella, Rhombopora lepidodendroides*	2
2. Shale, blue-black, homogeneous; *Nucula (ventricosa?)*,	

	FEET
Aviculopecten occidentalis, Nucula bellistriata, Monotis (gregaria?)	4
1. Limestone, gray, same fossils as in limestone above (Deer Creek)	2
	8

The lower limestone above mentioned is at the surface of the water below the dam, and is above the limestone at the bridge.

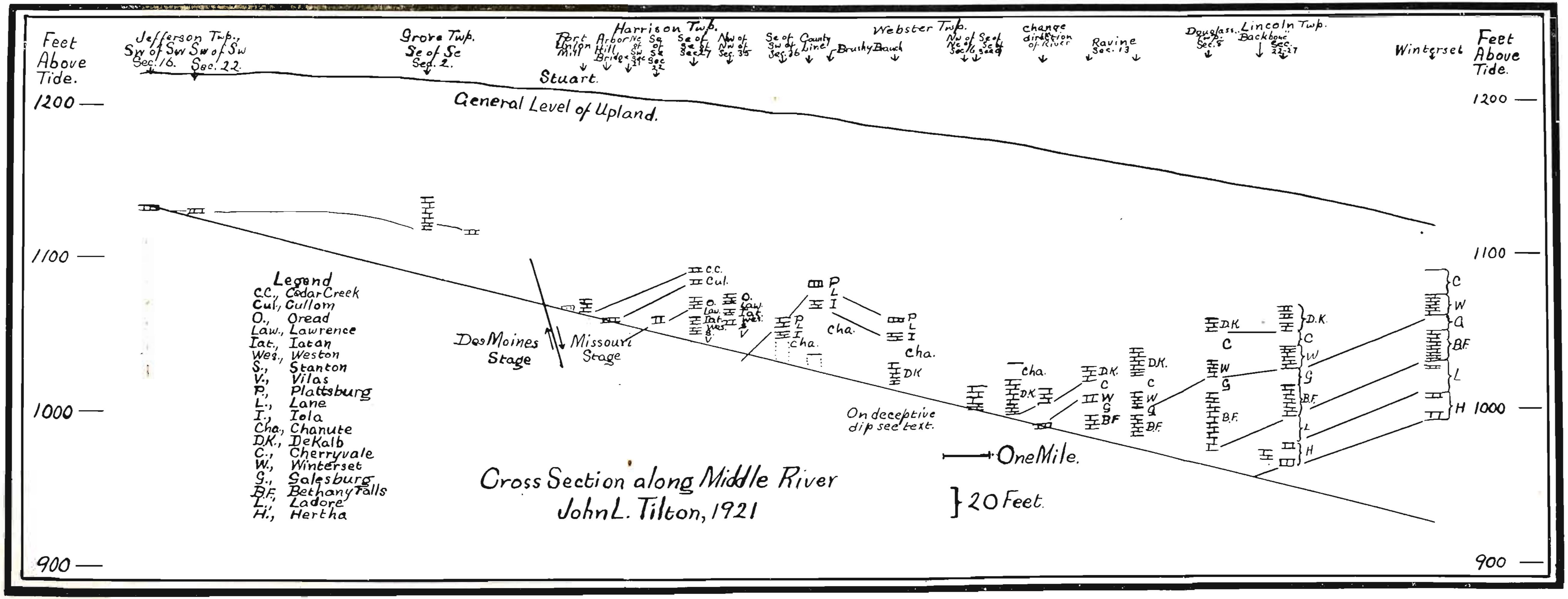
The distinctive layers of the Deer Creek limestone with *Fusulinas* and dark chert outcrop by the river side a mile northwest of Port Union mill (the northeast quarter of the southeast quarter of section 18, Harrison township). Close to the center of the next section west (13 of Grove township) fragments of a limestone appear that, traced northward along the river, attains a greatest thickness of outcrop a mile north (section 12) where it was formerly quarried. It is the base of this same limestone that outcrops by the bridge in the southeast quarter of section 21, Jefferson township, and lies just below the limestone that is at the level of the river in the southwest quarter of section 16, where it is fifty feet below Stuart, or at a level of 1,157 feet above sea level. In section 21 of Jefferson township the writer found *Marginifera muricata* (the index fossil of the Des Moines series), *Ambocelia planoconvexa, Composita subtilita, Hustedia mormoni, Spirifer cameratus,* also *Fusulina,* Bryozoa and coral. Gow's[69] description is as follows:

		FEET
10.	Drift	5
9.	Limestone, massive, unfossiliferous, weathering rectangular	4
8.	Shale, soft, light gray	1
7.	Limestone, buff to white, with narrow partings of light shale	2
6.	Shale, soft, light gray	5/6
5.	Limestone, similar to that next above	3
4.	Shale, soft, gray to brown	1
3.	Limestone, massive, without shale, *Composita subtilita, Productus nebrascensis, Spirifer cameratus*	3
2.	Hidden by alluvium	10
1.	Shale, hard, black	1/4
		30

This limestone is the upper limestone member (Pawnee) of the Henrietta division of the Des Moines series.[70] The river

69Geology of Adair county: Iowa Geol. Survey, Vol. XXVII, p. 288.

70The relation of the beds is discussed further in the Bulletin of the Geological Society of America, Vol. 33, p. 153, 1922.



The cross section along Middle river

crosses the Thurman-Wilson fault in the center of section 18, Harrison township, a mile up the valley from Point Union mill.

These various sections arranged in order with reference to the river bed give the accompanying cross section along Middle river.

The Structure of Southwestern Iowa.

The area as a whole is the northern limb of a syncline (strata concave upward) whose axis extends northwest-southeast through northwestern Missouri and northward into Iowa. The other limb of the syncline slopes upward toward the Ozark Mountains.[71] In southwestern Iowa the general dip to the southwest is so slight that it is often scarcely noticeable in short distances. The average obtained from Winterset to Clarinda is 8.6 feet to the mile or 4½ minutes.

Diagonally through the entire area runs a normal fault, known as the Thurman-Wilson fault, extending northeastward from the bluffs along Missouri river near Thurman, where the displacement is 300 feet, past Briscoe, where the displacement is 284.5 feet, to the northwest of Earlham. At present there is no information as to its presence from this point eastward. The fault has not been found in Nebraska.

Keyes[72] describes the Cap-au-gres fault seen on Mississippi river as extending northwest toward Leon, and possibly farther; but if it is present at all in Iowa it has not yet been re-

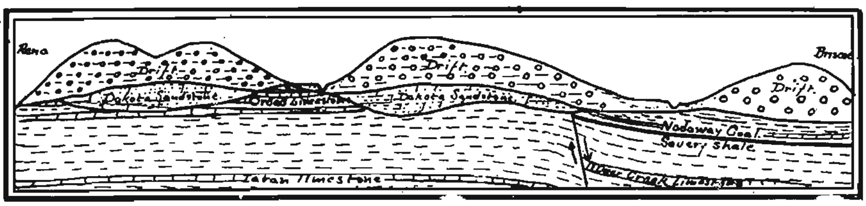


FIG. 49.—Diagram of conditions across the fault plane; from Reno, Edna township, Cass county, southeast to Briscoe.

cognized. He also represents a Pocahontas and a Fort Dodge fault, running southwest-northeast, parallel to the Thurman-Wilson fault; but the positions he designates lie beyond the area here considered[72a].

71See Hinds and Greene, The Stratigraphy of the Pennsylvanian Series in Missouri: Missouri Bur. Mines, Bull. XIII, p. 202, plate XXIII.

72C. R. Keyes, Controlling Fault Systems of Iowa: Proc. Iowa Acad. Sci., Vol. XXIII, p. 105.

72aF. A. Wilder discusses the structure of the Fort Dodge region on pages 173 to 177 of Volume XXVIII, Iowa Geological Survey, and James H. Lees has a paper on that same region, on pages 113 to 120 of Volume XXIX of the Proceedings of the Iowa Academy of Science.

Near the Thurman-Wilson fault the dip is very irregular. Parallel to the fault and on the west side of it lies the crest of a slight anticline (strata convex upward), distinctly seen in Montgomery and Cass counties, and also in Dallas county where Leonard described it years ago as the Redfield anticline,[73] without noting its relation to a fault. Close to the south side of the fault (the downthrow side) the strata, rising in general toward the northeast, curve off toward the west. This is particularly noticeable in the limestone members of the Kansas City stage near Earlham; but farther to the southwest this characteristic is not so noticeable because the strata are at a lower level with reference to the drift—they are exposed deeper in the valleys.

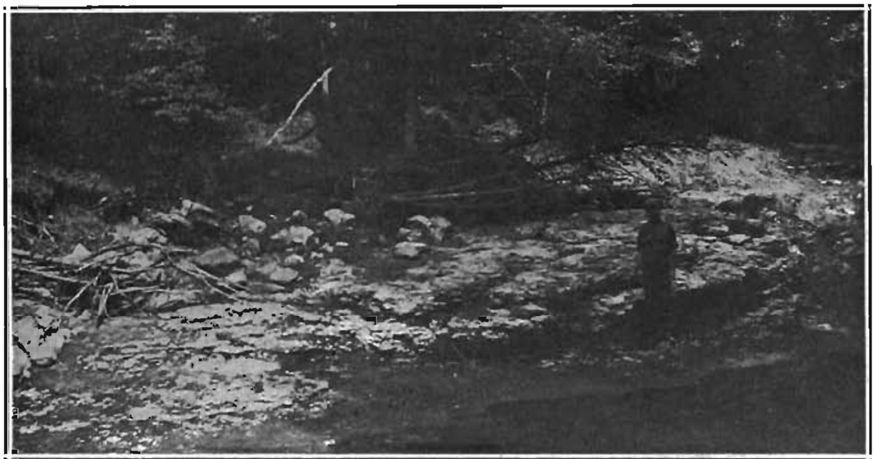


FIG. 50.—The uneven surface of the Winterset limestone in a ravine northwest of Osceola, Clarke county. (Township 72 north, Range XXVI west, southeast quarter of the southeast quarter of section 11.)

There are conditions that indicate an overlap with disconformity, and in one portion of the area an unconformity. In the northwest part of the area there is no evidence of the presence of the Kansas City stage, and it is the Lansing stage that there extends farthest toward the north. In the central and western part of the area the fossils and general character of the Oread limestone suggest that that limestone was laid down during the time of greatest advance, when marine conditions were most favorable to life forms, but in the northeast and northwest

[73] A. G. Leonard, Geology of Dallas County: Iowa Geol. Survey, Vol. VIII, p. 91.

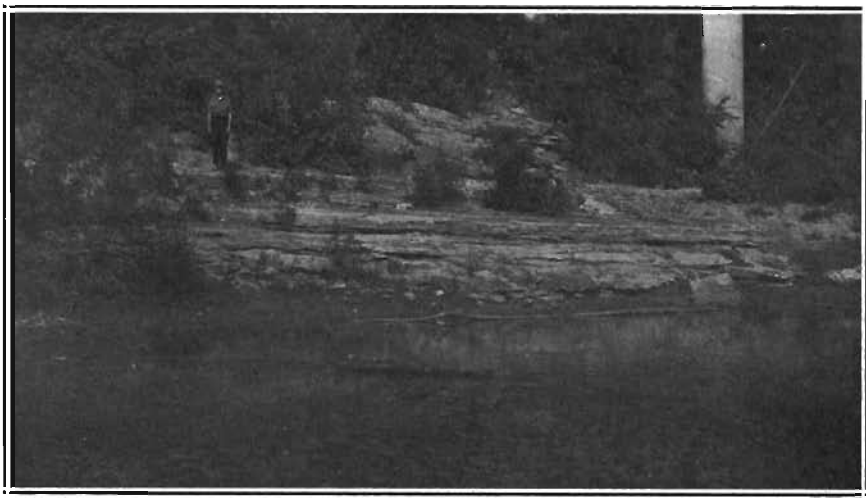


FIG. 51.—The surface of the Winterset at the bridge three and one-half miles west of Decatur City, Decatur county, where a slight unconformity is noted. The Winterset limestone is beneath the feet of the one in the picture. The limestone above this level is DeKalb limestone that has fallen down.

portions of the area the Oread is now absent. At the bridge over Grand river three miles west of Decatur City, in the eastern part of the area, there is a difference in dip between the Winterset limestone below and the De Kalb above. Here the distinctive beds of the Cherryvale shale, which are so noticeable south of Westerville and elsewhere, are concealed if they are present at all. Two miles west of Osceola and a little north the fragmental top of the Winterset limestone is eroded; and at Winterset there is at this horizon a yellowish apparently weathered stratum. These facts put together seem to indicate a local uplift near Decatur City followed by depression between the time when the Winterset was laid down and the time when the lower part of the De Kalb was laid down, which subsidence, either with or without slight warping, led to extensive overlap in the northwestern part of the area.

The general dip to the southwest is varied by a few gentle folds whose axes appear to run southeast-northwest, though there is much irregularity, especially near the fault. The exact number and the position of these folds it is difficult to determine from the few exposures of bed rock. One gentle anticline is the one previously noted three miles west of Decatur City, which apparently is a continuation of the one observed five miles north of Davis City. This possibly connects with the one seen along Middle river in sections 14 and 15, Webster township, Madison county. Another passes through Braddyville, Page county, lying a little to the north of the direction of an anticline which Hinds and Greene have located in Missouri as extending through Chariton, Livingston, Davies, Gentry and Nodaway counties, but apparently dying out before reaching Hamburg. Another syncline which is reported in Missouri would come midway between Decatur City and Braddyville, but it is not mapped as reaching Iowa. An extension of this line would pass near Brooks, Adams county. East of Brooks the dip is as usual in Iowa, to the southwest, with no reversal of dip noted southwest of Brooks. Between Braddyville and Hawleyville there is a syncline, and another slight one is present between McKissick grove and Nebraska City. There are also slight variations in dip that are noticeable as the strata are followed along the rivers.

DIP AND STRIKE

With the exception of the record in Dallas county and two measurements referred to in the footnote all records of measurements of dip[74] and strike have been obtained by the writer, using a Brunton hand transit to measure the dip or to determine the location of a horizontal line from which to measure. At some places the direction of strike (the direction in which the strata cut a horizontal plane) was not obtainable, but a component of the dip was seen in some particular direction. On the accompanying outline map such determinations are represented by dotted arrows. A few statements of direction of dip may be found in some of the county reports without record of the amount or exact direction of the dip. Of such a character is the statement of the dip at Braddyville.

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[74]Smith's statement of a steep dip to the north for outcrops near Stennett is a mistake. The Carboniferous Section of Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 636.

TABLE OF DIP AND STRIKE

County	Twp. N.	Range W.	Section	Place	Strike	Dip	Direction of Face of Outcrop	Dip in Direction of Outcrop
Guthrie	79	XXX	30-31	Belle Valley mill	N45°E	45°Se.		
Madison	74	XXVII	10	Peru quarry	N70°W	1°30'Sw.		
	75	XXIX	Se. of Nw. of 15				Downstream E	2¾'*
			N. half of Nw. qr. 14				Upstream W	2¾'*
	76	XXVII	Ne. of the Nw. qr. of 6				N34°W	2°50'
	75	XXVIII	W. center of 22				N6°30'W	1°30'
Adair	76	XXXI	Nw. of the Nw. of 11		N10°E	1°15'W		1°15'
Cass	76	XXXVII	Se. of the Nw. qr. of 9	Spring creek	N85°W	3°45'E		
			Nw. of the Sw. qr. of 10	Lewis	N85°W	3°45'E		
			Center of Ne. qr. of 1	Turkey creek		0°		
Clarke	72	XXVI	Nw. of the Nw. of 1 and Ne. of the Ne. of 11		N77°W	Av. of seven 4°6'W		
Union	71	XXVIII	Ne. of the Ne. of 14		N80°W	3°15'W		
			Ne. of the Sw. of 36		N85°W	1°45'W		
	72	XXVIII	Sw. of the Sw. of 28				N70°W	5°
Adams	73	XXXV	Se. of the Nw. of 3		N90°E	2°48'S		
			Nw. of Nw. of 6		N80°W	1°45'		
	71	XXXIV	Se. of Se. of 8		N32°W	3°15'S		
			Ne. of Sw. of 3				S47°W	2°
Montgomery	72	XXXVIII	Nw. of Nw. of 16	Riverview Park			S46°E	3°45'
			South center, 26				S20°E	30'
			Sw. of Sw. of 26		N 0°E	3°E		
Mills	73	XLIII	Sw. of Nw. of 29	Henton			S5°E	2°
Decatur	70	XXVI	Center of 28				S48°E	1°10'
	70	XXVII	Ne. of Se. of 20		N31°E	2°30'		
	68	XXVII	Se. of Se. of 25	Winterset limestone	N84°W	9°35'N		
				De Kalb limestone	N17°W N84°W	3°10'W 3°30'N		
Taylor	76	XXXV	Nw. of 21		N90°E	From 0° to 3°30' in ½-mi.		
Page	70	XXXIX	E. center of 36	Essex			N61°W	45'
	68	XXXVI	Sw. of Se. of 7	Mine	N57°E	1°S		
Fremont	70	XLIII	Ne. qr. of 14		N20°E	3°45'E		
	67	XLII	Center of 13		N30°W	3°W		
Nebraska City				Clay pit			N57°E	3°30'

* From estimates along a stretch of water.

TABLE SHOWING JOINTS

County	Twp. N.	Range, W	Section	Location	First Set	Second Set	Third Set
Madison	76	XXVII	Ne. of Nw. of 6	Bethany Falls ls. Ladore shale	N54°E	N58°42′W N58°42′W	N12°E
	75	XXVIII	Sw. of Nw. of 24		N53°E	N32°W	N4°W
Cass	76	XXXVII	Se. of Nw. of 9	Spring creek	N39°20′E	N20°40′W	
Pottawattamie [75]	74	XL	Nw. of Nw. of 23	Macedonia	N74°E, 83, 63, 86, 65, 65, 80. Av. 73°42′	N52°W	N31°E, 42, 13, 30, 13, 30. Av. 26°30′
			Se. of Se. of 3	Carson	N48°E, 69, 69, 53, 74. Av. 62°36′	N15°W, 14, 3, 15. Av. 11°45′	N 1°E 43 Av. 22°
	76	XLIV	West center of 26	Crescent	N70°E, 55, 56, 60, 80. Av. 64°12′	N35°W, 17, 32, 33, 30, 25. Av. 28°42′	
Montgomery	72	XXXVIII	South center, 26		N61°E 54	N35°W 52	N22°E
Mills	72	XLIII	Sw. of Sw. of 22		N90°E		N35°E
Decatur	70	XXVII	Sw. of Se. of 21		N58°E		
Taylor	70	XXXV	Nw. qr. of 21			N23°W	N21°E
Page	70	XXXIX	E. center of 36	Essex, Preston ledge	N68°E	N3°W	
Fremont	70	XLIII	Nw. of Se. of 26		N85°E		N30°E N40°E
	67	XLII	Center of 13			N80°W	N38°E
	68	XLI	Se. of Sw. of 33				N30°E
Average					N63°27.2′E	N31°29.8′W	N25°35.3′E

[75] The table of joints measured in Pottawattamie is from J. A. Udden, Geology of Pottawattamie County: Iowa Geol. Survey, Vol. XI, p. 268.

JOINTS

The directions of joints in the rocks have also been measured in various places using the same instrument as that used in determining the dip. One set of joints, that of the largest cracks, is parallel to the Thurman-Wilson fault, and one is about at right angles to the fault and parallel to the direction of the minor folds. Where several records have been made close together, as in Udden's list in his report on Pottawattamie county, it is the average that appears in the outline map. In the diagram the general directions appear in the averages, and the irregularity appears in the scattering of the individual records.

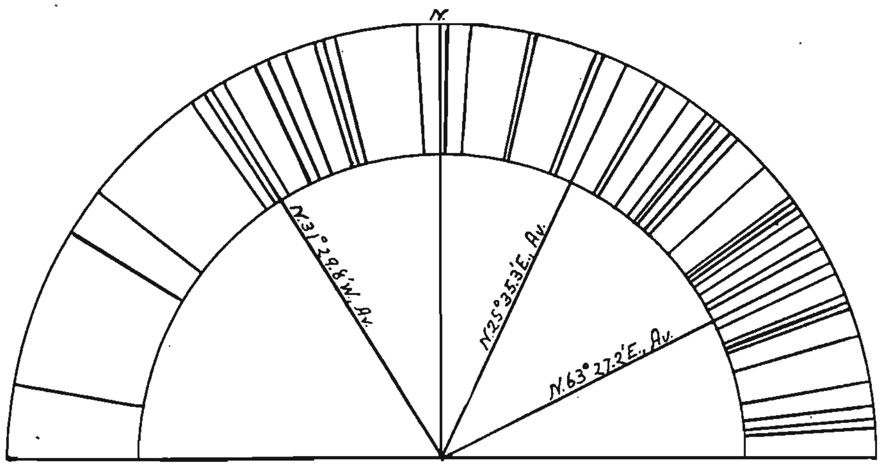
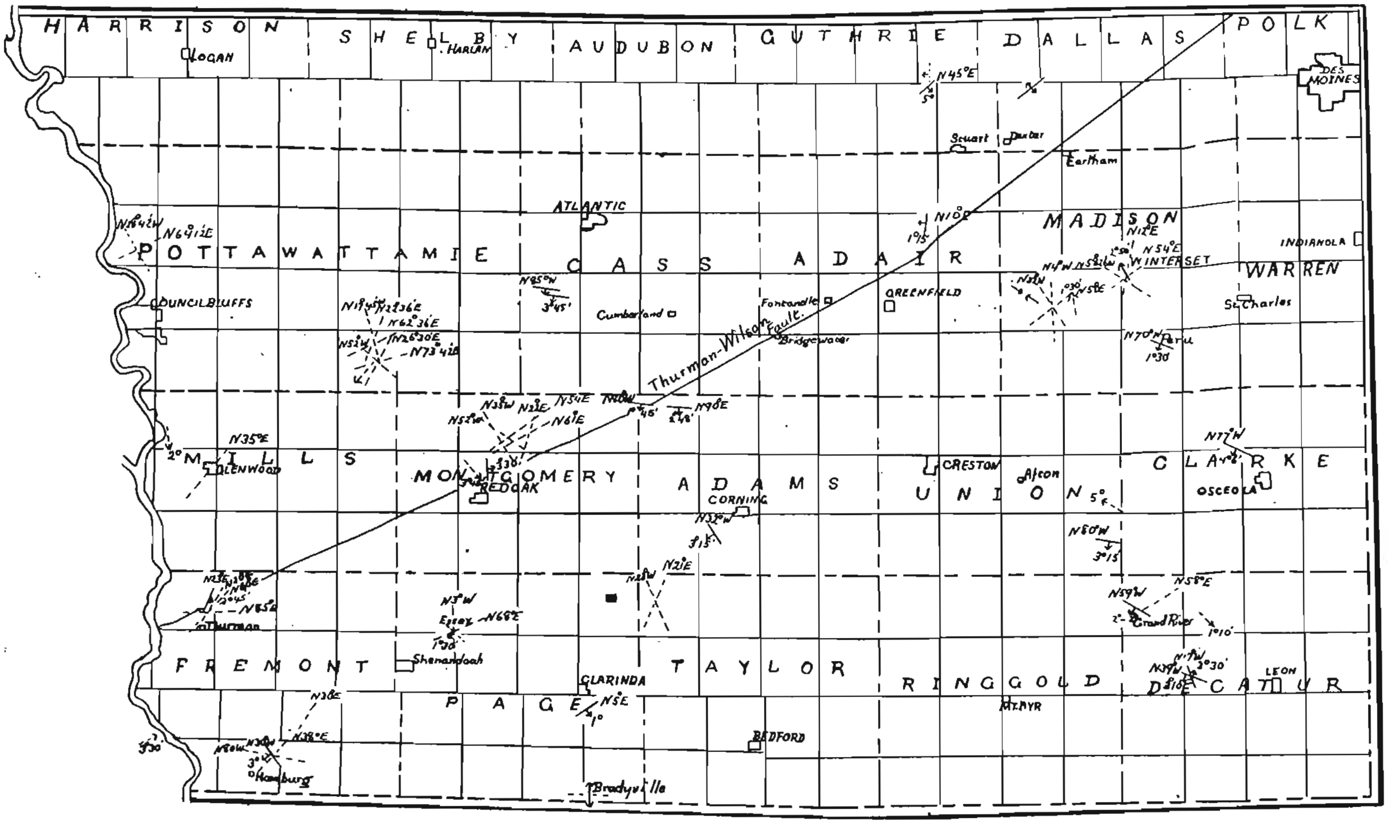


FIG. 52.—Diagram illustrating the directions of joints.

It is unfortunate that the drift conceals so much of the underlying rock as to make it impossible to work out all details of the gentle undulations that exist in the region. From what had been learned in the past the general position of the Nodaway coal had been determined. The latest important fact that has been ascertained is the reason for the absence of the Nodaway and Nyman seams from the area northwest of the Thurman-Wilson fault, except in a small area near Missouri river. This absence is due to the fact that the region to the north of the fault has been elevated and subjected to erosion, all of the Nodaway coal having been removed from that region, while to the south of the fault the region has been depressed and thus



Outline map giving the location of measurements of dip and strike, and of directions of joints. The dip and strike are represented in the usual way: (Strike) N45°W (Dip) 1°30′ The dotted arrows represent general direction of dip without measurement. The dotted lines represent directions of joints in the rocks.

the seam has been protected from the general erosion, so that now the coal extends as far east as where the plane of the coal, rising toward the northeast, reaches the plane of erosion that existed when the glacial drift was laid down. Such important facts it is in the field of geological work to discover. Further details come within the province of the miner, who from borings determines the local variations that exist in the position and thickness of the seams. It is from such details where the Nodaway coal has been mined and where it may be mined in the future that additional data on levels can be accumulated and reduced to barometric elevations. This can lead to an isobathic map of the base of the Nodaway coal, and this in turn to more exact knowledge of the minor folds that cross the area.

A knowledge of the location of minor folds is of importance to any who may seek to ascertain whether oil and gas exist in the deeper strata in this region in sufficient quantity to be of commercial value. The above list of locations of anticlines and synclines, though not extensive, is sufficient to guide an experienced oil man in determining where he should first sink a test well. At Clarinda the Cherokee shale is about fifty feet above sea level, and at Winterset it is about six hundred and fifty feet above sea level. Neither oil nor gas in commercial quantities has been reported from such wells as have been put down[76] and no seepage has been noted, though there are a few black limestone beds.

It is worthy of note that the deep well at Coin, though not quite along the axis of an anticline, is sufficiently well located to serve as a test well, although it is not very deep. It is reported to have reached salt water; oil and gas are not reported. The well is 888 feet deep and was sunk as a test well for coal and gas.[77] The bottom is about 680 feet above the Cherokee shale, which is here about 150 feet deeper than at Clarinda.

It is further worthy of note, from evidence presented by Dr. Alexander McCoy, with which evidence the data from southwestern Iowa are in agreement, that the Kansas City limestone grades into sandy shore deposits northward from Kan-

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[76]At Nebraska City, Glenwood, Coin, Clarinda, Bedford, Leon, Stuart.

[77]W. H. Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, p. 1158.

sas City toward southeastern Nebraska and southwestern Iowa; and that the western margin of this ancient sea is along a line of concealed granite hills or mountains[78] revealed by well records as extending southwest into central and southern Kansas.

The Areal Distribution in Iowa of the Divisions of the Missouri Series.

In tracing the areal distribution of the divisions of the Missouri series main reliance must be placed on the limestone in the southwestern part of the state. Where shale is the basal member of the division the area may extend for a short distance beyond the area of the limestone member, but generally not far. Often it is impossible to state the exact position of the margin because of the presence of Dakota sandstone and of drift. Where the margins are thus concealed it is possible to represent only the approximate general boundaries.

South of the Thurman-Wilson Fault line.—The eastern margin of the Kansas City stage is distinctly marked most of the way from Osceola to a point north of Earlham, where it stops at the fault plane. The representation of the position beneath the drift from Osceola to Leon is approximate. At Leon the deep well and a preglacial valley lie east of the Missouri series, the front of the Kansas City stage thus bending westward of Leon. No trace of the Hertha limestone, at the base of the Kansas City stage, was found east of Weldon river near the state line.

The locations of the eastern fronts of the various subdivisions are certain along a number of the streams that cause reëntrants in these margins, as on North, Middle and South rivers in Madison county, Squaw creek in Clarke county, and Grand river in Decatur county. Beneath the drift in the divides it is only the general direction of the eastern margin of the De Kalb limestone that can be inferred from relation to exposures from near Middle river to Grand river.

Likewise the eastern margins of the Lansing, Douglas and Shawnee stages may be satisfactorily determined in western

[78]A part of this information also comes from G. E. Condra of the University of Nebraska. See John L. Tilton, The Thurman-Wilson Fault through Southwestern Iowa, and its Bearing: The Journal of Geology, Vol. XXVII, p. 389.

Madison and eastern Adair counties, the chief difficulty there being to distinguish between the numerous limestones and shales. Farther south the main reliance is upon the line of well records from Nebraska City to Leon, which indicates where the subdivisions come up beneath the drift; but only the general directions of the margins can there be located. Farther west, in Page and Fremont counties, the Tarkio and Preston beds of limestone help to locate the position of the base of the Wabaunsee stage along the valley sides. Below this plane the valleys are cut down into the Shawnee stage. This is true in Missouri river valley also.

With the exception of the region near Bridgewater the line marking the eastern margin of the Nodaway coal is that of George L. Smith in his paper on "The Carboniferous Section of Southwestern Iowa," to which frequent reference has been made. The eastern border of the Nodaway coal marks approximately the eastern margin of the Howard limestone, the base of which, according to Beede and Rogers[79] marks a division between two faunas.

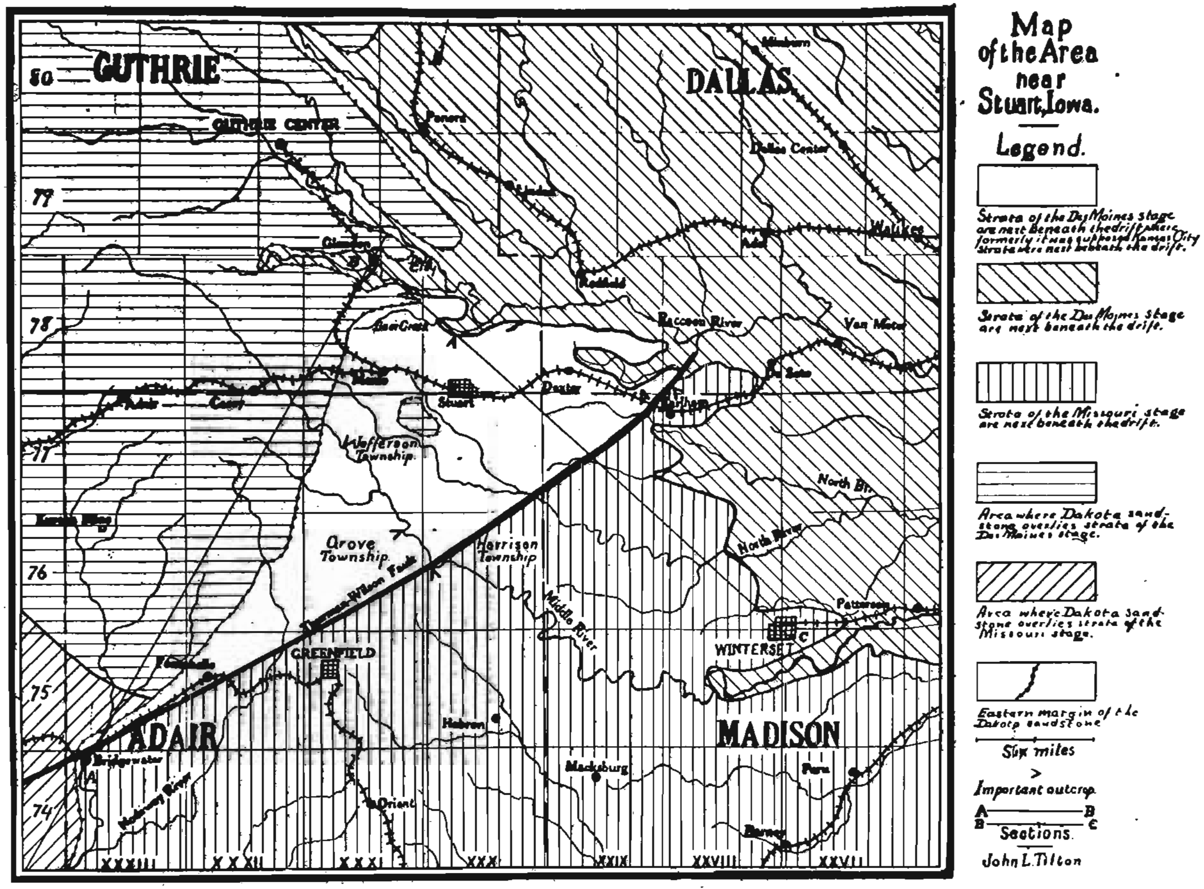
North of the Thurman-Wilson fault line.—The limestone near Stuart and the Eureka coal seam in the western part of Adair county having been correlated with beds deep in strata of the Des Moines series,[80] the eastern margin of the Missouri series is clearly farther to the west. See the map of the area near Staurt, Plate XXVII, also figures 53 and 54. In the record of the deep well at Atlantic[81] there is no evidence whatever of the presence of the various limestone members of the Kansas City stage; and yet the Oread limestone is clearly located five miles to the south on Turkey creek, and again at Fox quarry northeast of Grant. Whatever is concealed beneath the Dakota sandstone and the thick drift of the region must lie between Atlantic and these two points.

A further inference that has a bearing is dependent on

79J. W. Beede and A. F. Rogers, Coal Measure Faunal Studies: Kansas Univ. Geol. Survey, Vol. 9, pp. 345-346, 1908; also Hinds and Greene, Stratigraphy of the Pennsylvanian Series in Missouri, Missouri Bur. Mines, Bull. XIII, p. 183.

80John L. Tilton, The Strata near Stuart, Iowa: Bull. Geol. Soc. America, Vol. 33, p. 153, 1922.

81The record may be found in the following reports:
W. H. Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, Vol. XXI, p. 1121.
John L. Tilton, Geology of Cass County: Iowa Geol. Survey, Vol. XXVII, p. 257.



Map of the area near Stuart, showing distribution of the strata.

changes in strata north of Kansas City, Missouri. Near Kansas City the members of the Kansas City stage are as well or better developed than they are at Winterset and at Earlham; but to the northwest of Kansas City the strata grade into sandstone and shale, toward the old shore line, so that in the deep well record at Forest City, half way between Kansas City and the Iowa state line, the Kansas City stage is represented by sandstone and shale[82] instead of by limestone and shale. Thus

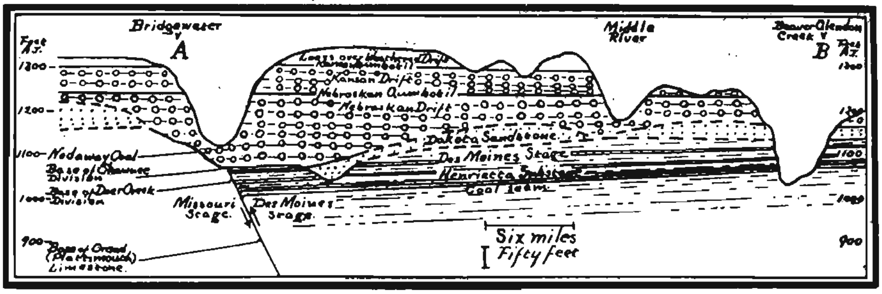


FIG. 53.—A Section from Bridgewater to Glendon, A to B on the map, Plate XXVII.

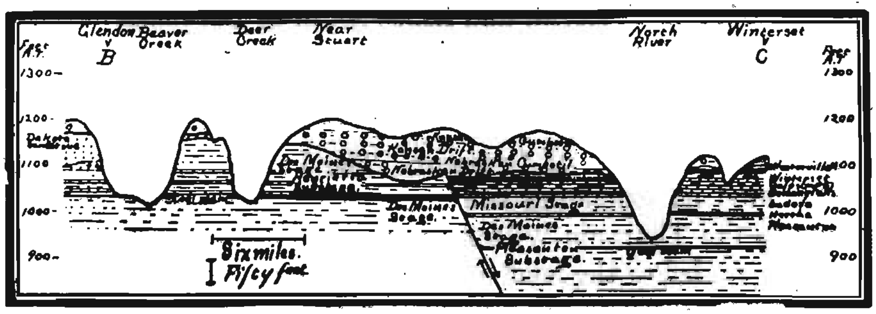


FIG. 54.—A Section from Glendon to Winterset, B to C on the map, Plate XXVII.

in Kansas City time the shore was not far away to the northwest and west. In northeastern Nebraska no outcrops of the Kansas City stage are recognized. The inference thus seems warranted that from Earlham toward the west shore conditions were more and more effective and that in the movements that gave us the Thurman-Wilson fault with accompanying erosion on the upthrow side these differing strata, from the conspicuous limestone beds at Earlham to the shales and sand-

82Dr. Alexander McCoy has reached this conclusion from the series of well records in eastern Kansas, and he presented his evidence to the writer when inquiring about the conditions in Iowa. The writer has studied the well records presented and has come to accept Doctor McCoy's conclusion. The evidence involves a different interpretation of the record of the Forest City well than that given by Hinds and Greene, Stratigraphy of the Pennsylvanian Series in Missouri, Missouri Bur. Geol. and Mines, Bull. XIII, pp. 215-239.

stones farther west, were eroded away. The erosion has thrown the present margin of the strata back toward the west about thirty miles. Nevertheless, somewhere between the Oread limestone outcrop south of Atlantic and the Eureka coal mine in northwestern Adair county there must lie, below the Dakota sandstone and the thick drift in that region, all that now remains of this portion of the Lansing and Kansas City stages. These stages are therefore assigned areas that are consistent with these facts.

The trend of the eastern margin of the Oread limestone toward the northwest and west seems to justify the representation of a similar trend in the margin of the Lansing stage. This involves the correlation of the limestone beds at Crescent. These beds lack the distinctive characteristics of the Oread limestone and their characteristics are judged to be in accord rather with those of the Lansing stage.

The border line between the Lansing and Douglas stages is clearly south of Crescent, and hence south of the place on Mosquito creek where White found exposed strata that are now concealed. These he correlated with the limestone found at Crescent.[83] The northern margin of the Lansing stage is thus placed not far north of Crescent. The Lansing stage is also represented as extending south under the Missouri river deposits to the Thurman-Wilson fault, since the valley evidently has been cut below the level of the Oread limestone, which is exposed south of Glenwood and at Henton.

There is an absence of exposures of stratified rock along the river valley from Crescent to near Logan, where well records reveal a widely distributed bed of limestone,[84] the position of which demands the following discussion.

Comparing Calvin's faunal list of fossils from the limestone at Logan, as reported by Shimek, with Udden's list for Crescent, in the report on Pottawattamie county, it is noted that *Campophyllum torquium* is reported at Logan but not at Crescent, that what is identified as *Productus* (*Marginifera*) *longispinus* is abundant at Logan but is wanting at Crescent, and

83C. A. White, Geology of Iowa, Vol. I, p. 379, 1870.

84B. Shimek, Geology of Harrison and Monona Counties: Iowa Geol. Survey, Vol. XX, p. 301-302.

that *Spiriferina,* found at Logan, also is wanting at Crescent. On the other hand, *Astrophyllum rude,* found at Crescent, is absent at Logan. So also are *Archeocidaris,* the bryozoans, and *Productus punctatus.* The other brachiopods that are present at both places are also found throughout both the Des Moines and Missouri series (up to the Wabaunsee stage). Not only do the faunal lists disagree to this extent but the records of the sequence of strata[85] also disagree, and the general dip of the strata places the limestone at Logan far below that at Crescent.

The next comparison is with the Kansas City stage, the beds of which, if present at all, lie beneath the Lansing stage. All the fossils named are reported here and there in the Kansas City stage either in Iowa or Missouri, and they are also found in the Des Moines series and in all the other divisions of the Missouri series, unless it be *Campophyllum torquium,* which has an uncertain distribution. The number (eight) of *Marginifera* (*Productus*) *longispina* reported from near Logan especially attracts attention, for this shell is not found in abundance in the Missouri series, while *Marginifera* (*Productus*) *muricata,* a shell much like it, does occur in great abundance in parts of the Des Moines series. Imperfect specimens of the two may look very much alike. However, *Marginifera longispina* is not to be considered an index fossil[86] of the Missouri

85For the record of the strata at Crescent see: J. A. Udden, Geology of Pottawattamie County: Iowa Geol. Survey, Vol. XI, p. 227. For the record of the strata near Logan see: C. R. Keyes, Coal Deposits of Southwestern Iowa: Iowa Geol. Survey, Vol. II, p. 437.

86Formerly it was thought in Iowa that *Marginifera (Productus) longispina* was as truly an index fossil of the Missouri series as *M. muricata* is of the Des Moines series, but literature with reference to *M. longispina* (and also *M. wabashensis*, a possible synonym) does not support that view.

Stuart Weller in Bulletin 153, U. S. Geological Survey, lists *Productus muricatus, P. longispinus* and *P. wabashensis* as three distinct species and *P. splendens* as a synonym of *P. longispinus.*

George H. Girty in his Palaeontology of the Pennsylvanian of Missouri (Hinds and Greene, Stratigraphy of the Pennsylvanian Series of Missouri: Missouri Bur. Mines, XIII, 1915, table p. 303 and text) lists *M. wabashensis* as found in Cherokee shales of the Des Moines series, doubtful in the Henrietta, and present in all divisions of the Missouri series excepting the Wabaunsee stage. He also mentions *M. muricata* (*Chonetes mesolobus,* etc.) as restricted to the Des Moines group (series). (*Idem.,* 281.)

In Iowa A. G. Leonard lists *Marginifera (Productus) longispina* as found with *M. muricata* and *Chonetes mesolobus* close to Adel. H. Foster Bain names it as being found in the limestone north of Stuart, and Samuel Calvin mentions it among the fossils found near Logan in Harrison county. In the last two places it was at the time supposed that the strata were in the Missouri series. As explained in this paper and in "The Strata near Stuart, Iowa," read before the Geological Society of America, December, 1921, it is now found that the strata are in the lower part of the Des Moines series. G. L. Smith in his earliest paper on "The Palaeontology and Stratigraphy of the Upper Carboniferous of Iowa" (Proceedings of the Iowa Academy of Science, Vol. XXII, 1915), names *P. muricatus* and *P. longispinus* as both found in the City Bluff shale. In a later paper (Idem., XXV, 535. 1918) he comments on criticism for identification of *M. muricata* in the Forbes (Deer Creek) and City Bluff shale, and in the table that follows lists *M. wabashensis* as a synonym for *M. longispina.* In his contributions published in 1916 (Idem., XXIII, 87) he had mentioned *M. longispina* as found near the Nyman coal, and *M. wabashensis* as found near Thurman. The locations at series for it is reported from both the Des Moines and the Missouri series.

Comparing the faunal list from Logan with the faunal list from north of Stuart,[87] it is noted that *Fusulina* (few at Logan) is not in the list from north of Stuart, and that *Campophyllum* likewise is absent; as are also *Productus punctatus, Spirifer kentuckiensis* and *Phillipsia major,* all of which are reported as being found in all of the subdivisions of both the Des Moines and Missouri series, except that *Campophyllum* has an uncertain distribution. *Phillipsia major* is listed as doubtful in the Henrietta formation.[88] The character of the strata at Logan, their position with reference to the Missouri strata to the south, and with reference to the Des Moines strata near Stuart to the east, give evidence that the strata at Logan belong to the Des Moines series.

Following what seems to the writer the proper conclusion, the margin of the Des Moines series, where it disappears beneath the Lansing stage, extends from near Atlantic northwest and then west to not far north of Crescent, leaving the area to the north for the location of Des Moines strata.[89]

The above description presents the physical basis for the plane separating two faunal units, one including the Kansas City stage, the other including the strata from the top of the Kansas City stage to the top of the Oread limestone.[90]

Thurman, at the Nyman coal and at the City Bluff beds are all in the Wabaunsee stage of the Missouri series, the division from which in Missouri Girty did not report that species.

F. B. Meek considered both *P. splendens* and *P. wabashensis* as synonyms of *P. longispinus.* ("Final Report of the U. S. Geological Survey of Nebraska," etc., 1872, 162.)

C. A. White thought both *P. muricatus* and *P. longispinus* ranged "through the whole of the Carboniferous or Coal Measure series." (U. S. Geological Survey West of the 100th Meridian, IV, 1877, 119 and 120.)

G. H. Girty in his report on the "Stratigraphy and Palaeontology of the Upper Carboniferous Rocks of the Kansas Section," (Bulletin 211 of the U. S. Geological Survey, 1903), lists *M. muricata* as found not only in the Cherokee, Fort Scott, Labette and Parsons members of the Des Moines series but also in the Deer Creek and Lecompton of the Missouri series. *M. wabashensis* he reports from twelve different horizons: two in the Des Moines series, nine in the Missouri series, and one in the Permian.

87Collected by Samuel Calvin; H. Foster Bain, Geology of Guthrie County: Iowa Geological Survey, Vol. VII, p. 447.

Note that the strata north of Stuart are correlated with strata deep down in the Des Moines series: John L. Tilton, The Strata near Stuart, Iowa: Bulletin of the Geological Society of America, Vol. 33, p. 153, 1922.

88Hinds and Greene, Stratigraphy of the Pennsylvanian Series in Missouri, Missouri Bur. Mines, Bull. XIII, pp. 302-307.

89Hinds and Greene's report on, "The Stratigraphy of the Pennsylvanian Series in Missouri" mentions five places that suggest conditions related to a disconformity close to the Cement City beds. They also note that in Jackson and Clay counties "a thin bed of impure coal in places appears in the Cherryvale shale above the Winterset limestone. One and a half miles east of Liberty the shale above the Winterset limestone "is suggestive of unconformity" (p. 128); and, while the report named does not mention it, the upper part of the Winterset limestone near Bethany Falls, Missouri, is even more conspicuously fragmental than it is at Winterset.

90Idem., pp. 116 and 155.

The Douglas stage is at the surface at Riverview Park north of Red Oak, at Fox quarries in Cass county, and on Turkey creek north of Lewis. Its northern border lies somewhat north of these points, and then curves into a direction approximately west to near Council Bluffs and then south along the Missouri bluffs to the Thurman-Wilson fault. The strata that used to outcrop near Malvern are now concealed, but the excellent description of them and their fossil content that Udden[91] prepared clearly identifies them with the beds about two miles southwest of Glenwood, at the railroad bridge over Keg creek. The Douglas stage is therefore represented as extending southward past Malvern to the fault line. The Douglas stage is also present in a narrow strip along the bluffs south of Glenwood to the Thurman-Wilson fault.

The Shawnee stage is well represented at Stennett in Montgomery county. With these beds are correlated the beds at Carson, Macedonia[92] and Henderson. Likewise north of the fault there is an area northeast of Thurman and around Tabor which contains coal that Smith[93] correlates with the Nodaway seam. Hence there is here represented an area of the uneroded strata of the Shawnee stage.

91J. A. Udden, Geology of Mills and Fremont Counties: Iowa Geological Survey, Vol. XIII, p. 157.

92Thus aggreeing with Udden: J. A. Udden, Geology of Pottawattamie County: Iowa Geol. Survey, Vol. XI, p. 230; but I cannot accept his correlation of the beds at Macedonia with those at Crescent, which is supported neither by sequence in character of the beds, nor by fossil content.

93George L. Smith, Carboniferous Section in Southwestern Iowa: Iowa Geol. Survey, Vol. XIX, p. 645.

NEW ECHINODERMS FROM THE MAQUOKETA BEDS OF FAYETTE COUNTY, IOWA

BY

ARTHUR WARE SLOCOM
AND
AUGUST F. FOERSTE

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NEW ECHINODERMS FROM THE MAQUOKETA BEDS OF FAYETTE COUNTY, IOWA

The specimens on which this second paper[1] on the paleontology of the Maquoketa Beds of Iowa is based, are taken from four collections, viz.: The Field Museum of Natural History of Chicago, The State University of Iowa, Walker Museum of The University of Chicago and the private collection of Mr. A. G. Becker of Clermont, Iowa, part of whose collection is now on deposit at Walker Museum. Part of the Field Museum specimens and nearly all of the Walker Museum specimens were donated by Mr. Becker. The balance of the Field Museum specimens and all of the University of Iowa specimens were collected by Mr. Slocom.

It was originally intended to have two papers on the Echinoderms, one on the Crinoids by Mr. Slocom followed by one on the Cystoids by Doctor Foerste, but as the work of preparation progressed it was found very desirable to have the benefit of Doctor Foerste's knowledge of certain genera of the crinoids, so at the request of Mr. Slocom, he agreed to take, besides the cystoids, two genera of crinoids. On account of this change, it was thought best to combine the two papers as parts one and two of a paper on "The Echinoderms." An unpublished description of a Pleurocystites from this horizon and locality, by Ulrich and Kirk, is included in part two.

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[1]The first paper is on the Trilobites, Field Mus. N. H., Geol. Series, 1913, vol. 4, pp. 43-83 and republished with slight revision, Iowa Geol. Survey, 1915, vol. XXV, pp. 187-237.

PART ONE

BY ARTHUR WARE SLOCOM

Classification and Terminology

The classification of the Crinoids prepared by Mr. Frank Springer and given in the revised English edition of Zittel's Textbook of Palæontology, 1913, is followed in this paper, and for definitions of the various orders and families, the reader is referred to that work. The terminology may be stated as follows:

Crinoid: A normal crinoid consists of a crown attached by its base to a stem or column, which is fixed to a solid body by a rootlike attachment.

Test or theca: The outer shell, composed of plates united by more or less close sutures.

Stereom: The shell structure or the material of which the test is composed, usually calcium carbonate.

Crown: All of the crinoid above the stem. It includes the calyx and the arms.

Calyx: The body of the crinoid without the free arms or stem. It includes the dorsal cup and ventral disc or tegmen, and within it are enclosed the more important organs of the body.

Dorsal Cup: That part of the calyx below the point of attachment of the free arms. It is usually more or less cup-shaped and is composed of two or more rows of plates having a more or less complete pentamerous symmetry.

Ventral Disc, Tegmen, Dome, etc.: That part of the calyx above the point of attachment of the free arms. It is made up of plates more or less regularly arranged and contains the mouth and usually the anal opening.

Base: That part of the dorsal cup lying between the radial plates and the stem. It consists of a single row of plates, the basals, in a monocyclic base, and of two rows of plates, the basals and infrabasals, in a dicyclic base.

Rays or Brachials: The series of plates which rest upon the basals and extend up to and form the arms. The first plate is always a part of the dorsal cup, the others may or may not be a part of the cup. There are five of these rays, except in the Zophocrinidae, and they are designated as follows: (Figs. 55 and 56) (1) *right posterior ray,* (2) *right anterior ray,* (3) *anterior ray,* (4) *left anterior ray,* and (5) *left posterior ray.*

Interbrachial areas (iBr[2]): The plates in camerate crinoids situated between the rays.

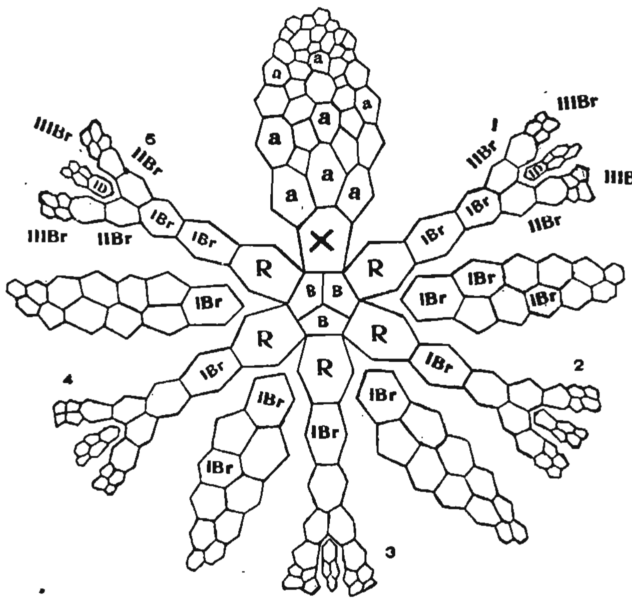

FIG. 55. Diagram of a Monocyclic Camerate Crinoid.

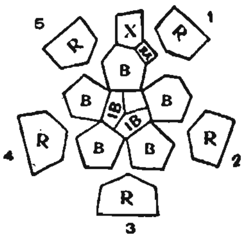

FIG. 56. Diagram of a Dicyclic Crinoid.

Anal, azygous or posterior interradius Xaa: The area situated between the right and left rays and leading up to the anal opening.

Basals (B): The circle of plates directly below the radials and alternating with them. In a monocyclic base they join the column.

Infrabasals (IB): The first row of plates in a dicyclic base. They separate the basals from the column and are radial in position.

Radials (R): The first plate of each ray, usually resting on the basals. In some families part of the radials are divided horizontally. The parts of these plates are called *superradi-*

[2]The letters in parentheses refer to those of figures 55 and 56.

als (Rs) and *inferradials* (Ri) respectively. (Fig. 58, p. 337.)

Primibrachs or Costals (IBr): Those plates of each ray extending from the radials, on which they rest, up to the first bifurcation.

Secundibrachs or Distichals (IIBr): All plates of each ray between the first and second bifurcations.

Tertibrachs or Palmers (IIIBr): All plates of each ray between the second and third bifurcations.

Intersecundibrachs (ID): Any plates situated between the secundibrachs.

Anal plate (X): First plate of the anal interradius. It often rests upon the posterior basal and is in line with the radials or nearly so.

Radianal (RA): A plate resting within the angle formed by two basals and below the right posterior radial plate. It joins the anal plate on the left and occupies the position of an inferradial.

Interbrachials (iBr): Any plates of the interbrachial areas.

Pinnules or armlets: Small jointed appendages which are given off alternately from opposite sides of the arms and usually are similar to the arms in appearance.

Stem or Column: The jointed appendages which connect the crown of a crinoid with the *attachment base*. It is composed of *segments* or *columnals* which are pierced by an *axillary canal* through which passes the ligament which holds the stem together. When speaking of the form of a stem, the transverse section is meant.

Brachioles: Food grooves on the ventral surface, leading to the mouth.

Distal: Farthest from the stem.

Proximal: Nearest to the stem.

Lateral: Pertaining to the side.

Archetype: The original form from which a class of related forms in plants or animals may be supposed to have descended.

Genotype: The species upon which a genus is based.

Primary types: All the specimens used by the author of a species for the description or figures.

a) *Cotypes*: All the specimens described or figured by the author of a species, provided no holotype is selected.

b) *Holotype*: The one of the types chosen and indicated by the author.

c) *Allotype*: A specimen selected by the author and illustrating another part of the organism from the holotype.

d) *Paratypes*: All specimens, other than the holotype or allotype, used in the description.

Supplementary or Hypotypes: Specimens described or figured after the original description to complete or correct it.

a) *Plesiotype*: A specimen from any locality used for a redescription or refiguring of the species.

b) *Metatype*: A specimen from the type locality and horizon and identified by the author.

c) *Plastotype*: An artificial cast or replica of a type.

Authors differ widely in the use of the terms "mold," "cast" and impression," but as used in this paper they may be defined as follows:

Natural mold: A cavity in the rock, or matrix, formed by natural causes, around an organism while the rock was plastic. The external form of the organism is thus preserved.

Natural cast: The rock filling of the internal or visceral cavity of an organism, the shell of the organism having served as a mold. In many cases the shell is afterwards dissolved out, leaving the mold and cast in position. In such cases the space between the two indicates the thickness of the shell.

Impression: An artificial cast, made in a natural mold, which shows the external features of the organism. Many kinds of materials have been used for making impressions; among them may be mentioned plaster, dental wax, printing roller composition and vulcanized rubber. The methods of making impressions from the two latter substances have been previously described by the writer.[3]

Descriptions of Genera and Species

Family **RHODOCRINIDAE** Roemer.

When this family was proposed by Roemer the distinguishing characters given were those of Rhodocrinus, the only genus then referred to the family. Some of these characters are of generic rather than of family importance and the description has since been somewhat modified.

[3]Science 1907, N. S. vol. XXV, p. 591.

The last discussion of the family, so far as is known to the writer, was that of Wachsmuth and Springer in 1894, but not published until 1897, at which time only ten Ordovician species, belonging to four genera, were recognized; of these *Rhodocrinus asperatus* Billings (now *Deocrinus asperatus*) had been for nearly forty years the only member of this family reported from an horizon lower than the Trenton. In December, 1894, Miller and Gurley described three species of *Archaeocrinus,* viz: *A. peculiaris, A. asperatus* and *A. parvus,* and in the following year, *A. knoxensis.* All these except *A. peculiaris* belong to the genus *Diabolocrinus* and are here so referred. In 1907 Hudson proposed *Deocrinus* and *Hercocrinus;* the former to receive *Rhodocrinus asperatus* Billings and the latter to receive three new species. In 1916 Weller described *Atactocrinus wilmingtonensis,* gen. et sp. nov., which made, with those described in this paper, a total of twenty-one Ordovician species, divided among seven genera. More than half of these species are of Chazyan age.

The following is a complete bibliography of the Ordovician species and the table gives their vertical distribution.

Archaeocrinus? delicatulus Hudson.

A. delicatulus Hudson, Bull. New York State Mus., 107, p. 129, f. 8, 1907. Chazyan

Archaeocrinus desideratus W. R. Billings.

A. desideratus W. R. B., Trans. Ottawa Field Nat. Club, 2, p. 249, 1885; W. and Sp., Mem. Mus. Comp. Zoöl. Harvard, 20, p. 257, pl. 10, f. 4 a, b, 1897; Bather, Treatise on Zool., pt. 3, p. 200, f. 125, 1900. Trenton.

Archaeocrinus lacunosus (Billings).

Glyptocrinus lacunosus Bill., Geol. Surv. Canada, Rep. Prog. 1853-1856, p. 261, 1857; idem, Decade 4, p. 61, pl. 8, figs. 3a-3e, 1859.

A. lacunosus W. and Sp., Proc. Acad. Nat. Sci. Philadelphia, 1881, p. 364; Mem. Mus. Comp. Zool. Harvard. 20 p. 255, pl. 10, fig. 1, 1897; Springer, Mem. Geol. Surv. Canada, 15P, p. 11, 1911. Trenton.

Archaeocrinus microbasilis (Billings).

Thysanocrinus (Rhodocrinus) microbasilis Bill., Geol. Surv. Canada, Rep. Prog. for 1853-1856, p. 264, 1857.

Rhodocrinus microbasilis Bill., Geol. Surv. Canada, Decade 4, p. 63, pl. 6, fig. 2, 1859.

A. microbasilis W. and Sp., Proc. Acad. Nat. Sci. Philadelphia, p. 364, 1881, Mem. Mus. Comp. Zool. Harvard, 20, p. 256, pl. 10, figs. 2a - c, 1897; Springer, Mem. Geol. Surv. Canada, 15P, p. 11, 1911. Trenton.

Archaeocrinus obconicus Slocom.

A. obconicus sp. nov. This paper. Maquoketa.

Archaeocrinus peculiaris Miller and Gurley.

A. peculiaris M. and G., Bull. Illinois St. Mus. Nat. Hist., 5, p. 17, pl. 2, figs. 1-3, 1894; Miller. North American Geol. Pal., 2d. App., p. 734, figs. 1209-1300, 1897. Chazyan.

Archaeocrinus pyriformis (Billings).

Thysanocrinus (Rhodocrinus) pyriformis Bill., Geol. Surv. Canada, Rep. Prog. for 1853-1856, p. 262, 1857.

Rhodocrinus pyriformis Bill., Geol. Surv. Canada, Decade 4, p. 61, pl. 6, figs. 1a - d, 1859.

A. pyriformis W. and Sp., Proc. Acad. Nat. Sci. Philadelphia, 1881, p. 364; Mem. Mus. Comp. Zool. Harvard, 20, p. 255, pl. 10, figs. 3a-b, 1897; Grabau and Shimer, North American Index Fossils, 2, p. 550, 1910; Springer, Mem. Geol. Surv. Canada, 15P, p. 11, 1911. Trenton.

Atactocrinus wilmingtonensis Weller.

A. wilmingtonensis Weller, Contrib. Walker Mus., Univ. of Chicago, vol. 1, No. 10, p. 239, pl. 15, figs. 1-10, 1916. Richmond.

Deocrinus asperatus (Billings).

Rhodocrinus asperatus Bill., Geol. Surv. Canada, Dec. 4, p. 27, pl. 1, figs. 4a - 4e, 1859.

Archaeocrinus asperatus W. and Sp., Proc. Acad. Nat. Sci. Philadelphia, 1886, p. 301.

Deocrinus asperatus Hudson, Bull. New York St. Mus. 107, p. 122, fig. 5, pl. 8, 1907. Chazyan.

Diabolocrinus asperatus (Miller and Gurley).

Archaeocrinus asperatus M. and G., Bull. Illinois St. Mus. Nat. Hist. 5, p. 19, pl. 2, figs. 7-9, 1894; Miller, 2d. App., North American Geol. Pal., p. 734, fig. 1296, 1297, 1897.

D. hieroglyphieus W. and Sp., Mem. Mus. Comp. Zool. 20, p. 252, pl. 10, figs. 5a-c, 1897. Chazyan.

Diabolocrinus knoxensis (Miller and Gurley).

Archaeocrinus knoxensis M. and G., Bull. Illinois St. Mus. Nat. Hist. 6, p. 34, pl. 3, figs. 12-15, 1895.

Diabolocrinus parvus (Miller and Gurley).

Archaeocrinus parvus M. and G., Bull. Illinois St. Mus. Nat. Hist. 5, p. 21, pl. 2, figs. 26-28, 1894; Miller, North American Geol. Pal., 2d. App. p. 734, fig. 1298, 1897. Chazyan.

Diabolocrinus perplexus Wachsmuth and Springer.
D. perplexus W. and Sp., Mem. Mus. Comp. Zool. Harvard, 20, p. 250, pl. 11, figs. 1a, b, 1897. Chazyan.

Diabolocrinus vesperalis (White).
Rhodocrinus vesperalis White, Proc. U. S. Nat. Mus., 2, p. 259, pl. 1, figs. 11, 12, 1880; 12th Ann. Rpt. U. S. Geol. Surv. Terr., p. 129, pl. 35, figs. 4a-b, 1883.
D. vesperalis W. and Sp., Mem. Mus. Comp. Zool. Harvard, 20, pp. 251, 262, pl. 11, figs. 1c-d, 1897; Wood, Bull. U. S. Nat. Mus., 64, p. 104, 1909.
Gilbertsocrinus americanus Troost, Proc. Am. Asso. Adv. Sci. 2, p. 61, 1850 (nom. nud.).
Lyriocrinus sculptilus Miller. (not Hall), Jour Cin. Soc. Nat. Hist. 5, p. 83, pl. 3, figs. 6a, b, p. 117, 1882.
Archaeocrinus sculptus W. and Sp., Proc. Acad. Nat. Sci. Philadelphia, 1885, p. 320. Miller, North American Geol. Pal., p. 225, fig. 250, 1889. Chazyan.

Hercocrinus beecheri Hudson.
Lyriocrinus beecheri Hudson, Bull. New York St. Mus. 80, p. 277, figs. 4, 5, pl. 3, figs. 1-4, 1905.
H. beecheri Hudson, Bull. New York St. Mus. 107, p. 127, 1907. Chazyan.

Hercocrinus elegans Hudson.
H. elegans Hudson, Bull. New York St. Mus. 107, p. 125, pl. 9, text fig. 6, 1907; Grabau and Shimer, North American Index Fossils, 2, p. 549, 1910. Chazyan.

Hercocrinus ornatus Hudson.
H. ornatus Hudson, Bull. New York St. Mus. 107, p. 127, pl. 10, text fig. 7, 1907; Grabau and Shimer, North American Index Foss. 2, p. 549, 1910. Chazyan.

Maquoketocrinus ornatus Slocom.
M. ornatus sp. nov. This paper. Maquoketa.

Raphanocrinus gemmeus Hudson.
R. gemmeus Hudson, Bull. New York St. Mus. 80, p. 280, fig. 6, pl. 2, figs. 1-5, 1905. Chazyan.

Raphanocrinus sculptus (Miller).
Glyptocrinus sculptus Miller, Jour. Cincinnati Soc. Nat. Hist. 5, p. 37, pl. 1, fig. 2, 1882; idem, 6, p. 224, 1883; James, idem, 19, p. 116, 1897.
R. sculptus W. and Sp., Mem. Mus. Comp. Zool. Harvard, 20. p. 260. pl. 10, fig. 3, 1897. Richmond.

Raphanocrinus subnodosus (Walcott).
Glyptocrinus? subnodosus Walcott, 35th. Rept. New York St. Mus., p. 208, pl. 17, fig. 3, 1883; Miller, Jour. Cincinnati Soc. Nat. Hist. 6, p. 227, 1883.
R. subnodosus W. and Sp., Proc. Acad. Nat. Sci. Philadel-

phia, p. 321, 1885; Mem. Mus. Comp. Zool. Harvard, 20, p. 259, pl. 11, fig. 2, 1897. Trenton.

	Chazyan	Trenton	Eden and Maysville	Richmond Maquoketa	Total
Archaeocrinus	2	4		1	7
Atactocrinus				1	1
Deocrinus	1				1
Diabolocrinus	5				5
Hercocrinus	3				3
Maquoketocrinus				1	1
Raphanocrinus	1	1		1	3
Total	12	5		4	21

Lack of representation in the Eden or Maysville is significant. Although, of course, no one would care to predict that no species referrable to this family will ever be found in these beds, there is reason to believe that in many Richmond forms the line of descent from the Trenton is not through the Maysville. Mrs. McEwan[4] finds this recurrence of Trenton forms in the Richmond also to be well illustrated in the Platystrophias.

The family may be defined as follows:

Dicyclic crinoids with lower brachials and interbrachials forming an important part of the dorsal cup. Radials separated all around by interbrachials. Infrabasals five; basals five. Anal area slightly and in many cases not at all different from those of the other interrays.

ANALYSIS OF ORDOVICIAN GENERA OF THE RHODOCRINIDAE

I. Anal interradius generally with additional plates.
  1. Arms biserial, branching.
    A. First interbrachial surrounded by supplementary plates.
      a. Interbrachials not continuous onto the tegmen; secundibrachs pinnulate, some of the pinnules incorporated in the dorsal cup.
      Tegmen composed of numerous small plates forming a basin, with margins at the arm bases; a central mound contains the anus; first secundibrachs bear a large pinnule which meets its neighbor over the interbrachials; interbrachial areas not uniform; anal

[4]Proc. U. S. Nat. Mus. 56, pp. 383-448.

area not clearly distinguishable............ ....Hercocrinus

Anus subcentral at the end of a tube; anal interradius differing but little from the others; intersecundibrachs present ....Deocrinus

b. Interbrachials continuous onto the tegmen; anus at the end of a tube; no intersecundibrachs .... Diabolocrinus

B. First interbrachials not surrounded by supplementary plates; anus without a tube; interbrachials numerous, continuous onto the tegmen; intersecundibrachs usually present .... Archaeocrinus

2. Arms uniserial, not branching..............Raphanocrinus

II. Anal interradius without additional plates, pentamerous symmetry not interrupted.

a. Secundibrachs not incorporated in the dorsal cup; interbrachials continuous onto the tegmen............ ....Maquoketocrinus

b. Basals, radials and first interbrachials about equal; right and left anterior interbrachials not in contact with the basals.....................................Atactocrinus

Genus **ARCHAEOCRINUS** Wachsmuth and Springer.

ARCHAEOCRINUS OBCONICUS sp. nov., Plate XXIX, figs. 10-13.

Type Specimens Nos. P.17106 and P.11265 Field Museum, Chicago.

The calyx is obconical or subovate, slightly constricted at the arm-bases, greatest width at the height of the second primibrachs, which is about equal to its length. Base dicyclic with a pentalobate canal. The surface of the plates is covered with rather indistinct, crowded, parallel, raised striae. On the infrabasals the striae are parallel to the lateral edges of the plates; on the basals, radials, interbrachials, etc., they are at right angles to the sutures and divide the surface into more or less regular rhombs whose shorter axes are the lengths of the various edges of the plates and whose longer axes connect the centers of the adjoining plates. Sutures very inconspicuous. Aside from the striae, there are five rather broad, ill-defined ridges which originate at the columnar facet, follow the sutures between the infrabasals and extend across the basal plates, forming an obtusely pentagonal base. The surface of the natural cast indicates that the inner surface of the plates bore many irregularly placed nodes and that the median line of each ray was marked by a rather wide groove, but no indication of either the nodes or the grooves is visible on the outer surface of the plates.

Infrabasals five, equal, higher than wide. Basals five, heptagonal, truncated above at their meeting with the first interbrachials. The basals are the largest plates in the calyx and with the infrabasals form a cup having a width about twice its height. Radials five, pentagonal, except the left posterio-lateral, which is hexagonal, having one side in contact with the second row of plates in the anal interradius, pointed below. First primibrachs hexagonal, about the size of the radials. Second or axial primibrachs about half the size of the first, heptagonal, bearing on their superior edges the secundibrachs, only the first pair of which are preserved in the type specimen but, as these give no evidence of arm-facets, there probably were others separated by intersecundibrachs. First interbrachials heptagonal, somewhat larger than the radials, in contact with the basals, thus separating the radials from each other, followed by two plates in the second row and three each in the third and fourth rows. The anal area is wider than the other interbrachial areas; the anal plate is followed by three plates in the second row. The upper part of the anal area is missing in this specimen.

Measurements:

Holotype:	Diameter on anterior axis	21.0 mm.
	Diameter on lateral axis	18.0 mm.
	Diameter at top of basals	15.2 mm.
	Height to top of axillary primibrach	21.6 mm.
	Height to top of basals	7.1 mm.
Allotype:	Diameter at top of basals	17.1 mm.
	Height to top of basals	8.6 mm.
Estimated measurements of a complete calyx:		
	Diameter on anterior axis	23.0 mm.
	Height over all	24.0 mm.

This species resembles *A. pyriformis* (Bill.), from the Trenton of Canada, in having the infrabasals visible in a side view of the calyx instead of being situated in a concave base, as in other species. It differs from *A. pyriformis* in having two pairs of secundibrachs in each ray instead of six pairs, in the ornamentation and the relative size of the various plates.

The holotype is a nearly complete natural cast in chert (P. 17106) on which the sutures are well marked; the allotype (P. 11265) has the following plates preserved: the infrabasals, the basals, two radials and an interbrachial. Both specimens are in the collections of the Field Museum of Natural History. The former was donated by Mr. A. G. Becker and the latter was collected by the writer.

Horizon and locality.—Lower Maquoketa beds at Clermont.

Genus **MAQUOKETOCRINUS** gen. nov.

Base dicyclic. Pentamerous symmetry complete; anal area not distinguishable from the other interbrachial areas. Infrabasals five. Basals heptagonal, truncated above where they join the first interbrachials thus separating the radials from each other. Radials pentagonal, pointed below. Primibrachs two in each ray, the second or axillary plate having arm-facets on its distal edges. Secundibrachs not incorporated in the dorsal cup. Column, judging from the columnar facet, round with a pentagonal canal.

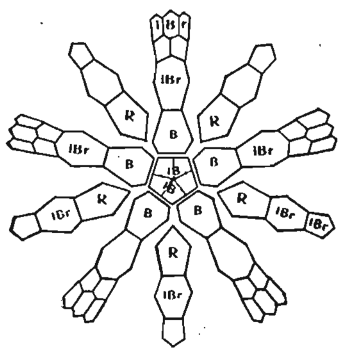

FIG. 57. Diagram of *Maquoketocrinus*

This genus belongs to the group of the Rhodocrinidae having no extra plates in the anal area. The group includes the American genus *Lyriocrinus,* from the Silurian, and the European genera *Anthemocrinus* from the Silurian and *Rhipidocrinus* from the Eifel. This genus is distinguished from the other members of the group by the absence of secundibrachs in the dorsal cup.

MAQUOKETOCRINUS ORNATUS sp. nov., Plate XXX, figs. 12, 13.

Type specimen No. P. 16840 Field Museum, Chicago.

The calyx is cup-shaped, height equal to its diameter at arm-bases, having a flat base with sides expanding at first abruptly and then gently to the arm-bases. Base dicyclic. Pentamerous symmetry complete, anal area not distinguishable from the other interbrachial areas. The plates of the dorsal cup are slightly convex and are ornamented with raised lines usually radiating from a central node and meeting the sutures at right angles, where they join similar lines from adjoining plates; many of these lines become obsolete before reaching the central nodes. Besides these radiating lines there are ridges composed of two or more parallel, raised lines which originate at a point a little below the center of each basal plate and extend laterally until they meet the ridges from the adjoining basals, thus forming a transverse ridge subparallel to the proximal edges of the basal plates. Two similar ridges extend obliquely from these subcentral points to the centers of the adjoining radials where they unite with ridges from another basal and continue along each ray, becoming more prominent until, at the distal edges of the axillary primibrachs, they form a pronounced protuberance which bears the arm-facets. Sutures indistinct.

Infrabasals five, equal, about half of their length extending beyond the column. Together they form a flat pentagonal disc, with a slight concavity for the reception of the stem. Basals five, equal, a trifle smaller than the radials, heptagonal, with their distal edges truncated where they join the first interbrachials. Radials five, equal, pentagonal, about equal in size to the first interbrachials. Primibrachs two to each ray; the first hexagonal, nearly as large as the radials; the second an axillary plate, pentagonal, higher than wide, bearing on its superior edges oblique facets for the attachment of the free arms. Secundibrachs not incorporated in the dorsal cup. First interbrachials about equal in size to the radials, resting on the basals, thus separating the radials from each other, followed by two smaller plates in the second row and others in the third row, which appear to connect with the plates of the tegmen. Column, judging from the columnar facet on the infrabasals, round with a pentagonal canal.

The above description is based on a single specimen, the holotype, (P. 16840) in the collections of the Field Museum of Natural History, a nearly complete dorsal cup having the arms, tegmen and stem missing.

Horizon and locality.—Lower Maquoketa shale, Clermont. Collected and donated by Mr. A. G. Becker.

Family CYATHOCRINIDAE

Subfamily CARABOCRININAE

Genus POROCRINUS Billings

"*Generic Characters.*—Cup composed of three series of plates, with one or more small interradials on one side and with a number of poriferous areas similar to pectinated rhombs of the Cystidea.

"In this genus there are five pelvic plates, five subradials, and five first primary radials alternating with each other, as in Poteriocrinus, Cyathocrinus and other allied genera. The principal new character upon which the genus is founded consists in the presence of poriferous areas." (Billings, Geol. Surv. Canada, Rpt. Prog., 1853-56, p. 279, 1857.)

In his discussion of *P. conicus,* Billings refers to the poriferous areas as probably having the same function as pectinated rhombs although differing in form and position on the plate. He says the pores consist of fine elongate parallel slits, which appear to penetrate the plates.

Zittel considered the so-called poriferous areas to be pectinated rhombs and referred the genus to the cystidean family Cryptocrinidae. (Handb. Pal., I, p. 420, 1879.)

Bather recognized that the angles of the plates consisted of series of folds and not of openings through the plates. He considered *Porocrinus* to be a dicyclic, Inadunate crinoid and placed it in the family Palæocrinidae. (Treatise on Zoology, pt. III, p. 172, 1900.)

Springer places *Porocrinus* in the subfamily Carabocrininae of his Inadunata Fistulata. (Zittel-Eastman Textb. Pal., p. 217, 1913.)

The generic characters, as now understood, may be stated as follows: Calyx obconical to globular; base dicyclic; column composed of thin segments rapidly decreasing in size from the calyx. Infrabasals five; basals five; radials five with narrow, well defined facets; arms uniserial, not branched; axial canal not separate from the ventral groove; anal plate in line with the radials; radianal rhomboidal, not separating the right posterior radial from the right posterior lateral basal. Tegmen composed of five rather thick orals, the posterior one a madreporite, which support the ambulacra on their adjacent edges and surround the pentagonal peristome; anal opening situated between the anal, posterior oral and the superior lateral edges of the posterior radials, no anal tube. Deep folds lie at the angles of the plates directed towards the angles and not passing at right angles across the sutures nor forming openings through the plates. (See Pl. XXX, fig. 14.)

POROCRINUS FAYETTENSIS sp. nov., Plate XXIX, figs. 14-22; Pl. XXX, fig. 14.

The type material upon which this species is based consists of five complete calyces free from the matrix, one calyx attached to the matrix and having parts of an arm and stem in position, a complete natural cast, two pieces of stem, and a number of separate plates; of these, the holotype (U. C. 24700), is in the collections of Walker Museum, of the University of Chicago; three calyces (P.11262, 16935, 17000), a natural cast (P.16841) and stems (P.11135) are in the collections of the Field Museum of Natural History; two calyces (Nos. 3694, 3695) are in the collections of the State University of Iowa.

The calyx is subglobular, aside from the ornamentation. The plates of the dorsal cup, above the infrabasals, are ornamented with central nodes from which rounded ridges extend to the middle of each edge of the plate and join the ridges from the adjoining plates. On the infrabasals, the ridges cross the plates, forming the edges of the columnar facets, then follow the sutures upward joining the ridges on the basals. The angles of the plates are made up of series of folds; the middle fold bisects the angle of the plate and the others are parallel to it. Sutures not situated in grooves; surface of plates finely granular. Arms five, not branched. Column obtusely pentagonal, diminishing rapidly in size from the calyx; segments thin, crenulated on their superior edges; canal roundly pentalobate (fig. 22). The natural cast is in the form of an elongate spheroid slightly flattened laterally. The impressions of the folded areas at the corners of the plates, the sutures, and the openings through the ventral disc are well preserved.

Infrabasals five, about equal in length and width, forming a shallow cup. Basals five, the two posterior ones heptagonal, the others hexagonal, about equal in size to the radials. Radials five, the anterior and two anterio-laterals hexagonal, the two posterio-laterals heptagonal; arm-facets elliptical, occupying not more than one-fourth the width of the radials. Radianal quadrangular, resting on the edges of two basals and supporting on its superior edges the right posterior radial and the anal plate. Anal plate pentagonal, resting on the posterior basal and the radianal, between the two posterior radials. Anal opening in line with the arm-bases and bordered by the thickened, excavated edges of the two posterior radials, the posterior oral and the anal plate. No anal tube. The tegmen is covered by five thick orals which support the ambulacrals and surround the peristome, which appears to be somewhat smaller than the anal opening. The posterior oral is a madreporite, being pierced by a hydropore.

Measurements.—As all the specimens observed have the lateral diameter of the calyx shorter than the anterior, it would seem to be the natural form of the calyx. Most of the specimens are complete and show no evidence of being crushed.

	HEIGHT	ANTERIOR DIAMETER	LATERAL DIAMETER
The holotype	9.8 mm.	9.4 mm.	8.4 mm.
The cast	8.5 mm.	7.9 mm.	7.5 mm.

Single plates belonging to this species were found which are nearly twice the size of the corresponding plates on the types.

In form and general appearance this species somewhat resembles *P. pentagonis* W. & M. but the basal plates are smaller in proportion to the radials, the calyx is rounder at the base and the stem is pentagonal instead of round, as in that species. *P. crassus* M. & W., reported from the Maquoketa beds of Illinois, possesses little resemblance to this species; the sutures are situated in grooves, the folded areas are sunken and the calyx is much more robust.

Horizon and locality.—Lower Maquoketa shale, Clermont and Bloomfield.

Family **DENDROCRINIDAE** Bather

Genus **DENDROCRINUS** Hall

Calyx obconical, unsymmetrical. Infrabasals five, equal, extending beyond the column. Basals five, large; four, hexagonal, and equal in size, the posterior one heptagonal, truncated by the anal plate. Radials five; simple in four rays, about equal in size, the right posterior one much smaller, separated from the basals by the radianal. Anal plate large, in line with the radials. Arms long and branching; ambulacral furrows deep; no pinnules. Ventral sac strongly developed, composed of numerous small, hexagonal, alternately interlocking plates of about equal size. Column usually pentagonal.

Dendrocrinus kayi sp. nov., Plate XXIX, figs. 1-4.

Calyx irregularly obpyramidal, increasing abruptly in size from the columnar facet to the middle of the basals where it is pentangular in transverse section, while the transverse section at the arm bases is hexangular, the angles being furnished by the five arm bases and the anal ridge. Anal area very wide, the distance between the posterior arms being more than twice that between any other two adjacent arms; this makes the anterior-posterior diameter of the calyx much less than the lateral diameter; height somewhat less than the longer diameter at the arm bases. The calyx is ornamented by several series of ridges, the most prominent of which originate at the columnar facet and follow the direction of the sutures between the infrabasals upward to a point near the middle of the basals where they bifurcate, forming a node, and extend obliquely upward across the radials to the arm bases where they meet ridges from the adjoining basals, except in the right posterior ray where these ridges join on the radianal plate and continue across the radial to the arm base. These ridges are continuations of angles of the column and are most prominent at the base. Another series consists of two or three threadlike parallel ridges which extend transversely between the basal nodes. These with the other series divide the surface of the calyx into a number of more or less concave triangles; three rather indistinct ridges extend inward from the angles and meet at the center of these triangles, which is also the meeting-place of the sutures between the plates. Six parallel ridges connect the arm bases near the tops of the radials but these ridges do not cross the azygous area; on the azygous area a prominent ridge extends upward from the node on the posterior basal across the anal plates up on to the ventral sac. Height of the calyx at the anterior ray 11.0 mm.; anterior-posterior diameter at arm bases 9.1 mm.; lateral diameter 12.5 mm.

Infrabasals five, equal, pentagonal. Basals five; four hexagonal, about the size of the radials, the posterior basal heptagonal, truncated distally by the anal plate and the largest plate in the calyx. Radials five; three hexagonal, two pentagonal; right posterior radial smaller than the others, being truncated proximally by the radianal plate. Together with the left posterior radial it supports the ventral sac. Arm facets prominent, occupying less than half the width of the radials. Arms uniserial, branching, primibrachs three to five in each ray; secundibrachs six to eight pairs; tertibrachs present but number unknown; no pinnules. First anal plate hexagonal, about twice as wide as high, resting on the posterior basal and between the two posterior radials, from whose superior edges rise the plates of the ventral sac. Radianal pentangular, resting on the superior edges of the posterior and right posterior basals and supporting the right posterior radial which it separates from the basals. Ventral sac transversely elliptical in section, plates small, hexagonal, width several times their height, grouped in a number of alternately interlocking vertical series; surface ornamented with well defined longitudinal ridges passing along the middle of each series of plates. These ridges are connected by fine threadlike oblique ridges so placed as to give a zigzag appearance. Length of ventral sac unknown, the portion preserved on the holotype extends twenty-seven mm. above the arm bases. Column, judging from the columnar facet, pentangular with a quinquepartite canal. Stems like the one figured are comparatively abundant in the shales in which the holotype was found and as the section of the base of the calyx and that of this column are similar there seems to be little doubt that they belong to the same species. The column is acutely pentagonal in its upper portion and gradually changes to a regular pentagon lower down. The segments of the column are relatively thin and are arranged in pairs consisting of a very thin segment and one about four times as thick with rounded nodes at the angles. The sutures between the segments form wavy lines.

This species somewhat resembles *D. casei* from a similar horizon in the Ohio Valley but the ridges are fewer in number and more prominent, the proportions of the height to the width of the calyx are different and the primibrachs and secundibrachs of a much smaller specimen consist of about a half more plates than in this species.

Horizon and locality.—The holotype, the only specimen known, was collected by Mr. A. G. Becker in the Upper Maquoketa shale at Patterson's Springs, near Brainard. The specimen is a part of Mr. Becker's collection but is now on deposit in Walker Museum, The University of Chicago.

Family **HETEROCRINIDAE**

Genus **ECTENOCRINUS** S. A. Miller

General form very elongate; calyx small, subcylindrical, moderately expanded; basals five, unequal; radials irregular, four plates in three series before the bifurcation of the free arms, and three in each of the other two series; arms ten, long; pinnules strong; azygous plates three, following each other, but not in a direct line; vault unknown; column very long, round, tripartite, and attached by an expanded base. Genotype, *E. simplex* (Hall). (Original description, North American Geol. & Pal. p. 242). To this may be added; secundibrachs syzygal, forming pairs of which the distal plate only is pinnulate; anal tube straight and narrow.

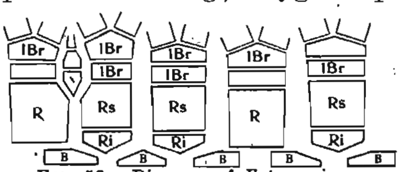

FIG. 58. Diagram of *Ectenocrinus*

ECTENOCRINUS RAYMONDI sp. nov., Plate XXIX, figs. 5-9.

Type specimen number 24701, Walker Museum, The University of Chicago.

The calyx is small, obconical, regularly tapering, height to the top of the radials somewhat less than the width at that place. Surface of the plates smooth, sutures rather inconspicuous, not situated in grooves. Arms ten, subcircular in section, uniserial, composed of plates having their length about half their width and edges nearly parallel near the bifurcation but much shorter and cuneiform farther up. These plates are in pairs of which the distal plate only is pinnulate, the pinnules being on alternate sides of the arm so that there is a pinnule on each side to every four arm-plates. The lateral margins of the arms are marked with shallow, rounded grooves which are at right angles to the axis of the arms. These grooves are situated on the sutures, and many of them are on alternate sutures but in some cases they are on intervening sutures while in others there are two sutures between grooves. On the first examination these grooves appeared to be sockets for the attachment of the pinnules but upon further study they seem to become obsolete before reaching the ventral margin of the arms where the pinnules are attached and also they are more numerous than the pinnules. (Figs. 8 and 9.) Stem circular, composed of thin segments, gradually diminishing in size from the base of the calyx; canal tripartite.

Basals five, the right posterior lateral regularly pentagonal, the others irregularly so. Radials five, the largest plates in the calyx. The anterior one is hexagonal, the left posterior radial is heptagonal, but neither of these possesses an angle on its proximal edge where it joins the basals. The other three radials are compound, the inferradials are pentagonal, pointed below, width more than twice the height, the superradials are quadrangular except the right posterior which is pentagonal, the extra side on each of the posterior radials is caused by contact with the anal plate. Primibrachs two to each ray, the first rectangular, the second, an axillary plate, pentagonal, both wider than high. Secundibrachs many, either rectangular or cuneiform. The anal series consists of three plates, the first pentangular, resting between the distal edges of the posterior radials, followed by a larger hexangular plate which supports a very small plate which appears to be quadrangular. Other anal plates and the ventral sac are invisible, being covered by the arms.

Measurements.—As the specimen is somewhat crushed laterally, the first measurement is estimated:

Diameter of calyx at top of the radials	6.0 mm.
Diameter of the base of calyx	3.8 mm.
Diameter of stem 10 mm. below the base	2.0 mm.
Height from base to top of radials	4.5 mm.
Height from base to top of axillary primibrachs	7.1 mm.

Of the three known species of the genus, this species approaches *E. grandis* (Meek) from the Eden and Lower Maysville beds of the Ohio Valley. In size, plate formulae and general proportions they are similar but in *E. raymondi* the arm-plates are shorter in proportion to their width and the pinnules are more slender. The most conspicuous character is the presence of transverse grooves on the lateral margins of the arms and the fact that the dorsal margins of the arms are arcuate in this species and flattened in *E. grandis*.

The holotype was collected by Dr. P. E. Raymond of Harvard University and the specific name is given in his honor.

Horizon and locality.—Lower Maquoketa limestone at Clermont.

HETEROCRINUS? Plate XXX, figs. 15-17.

A number of attachment bases which seem to belong to the above or a closely related genus are in these collections. All were attached to some object when alive but the larger ones have since been separated. They vary in size from 5 to 28 mm. across their radicular expansions and from 1 to 9 mm. in height. The attachment area for the column is circular, more or less concave in the larger specimens, and marked with well-defined ridges radiating from the center.

The largest specimen observed (fig. 16) is shown natural size. It measured 28 mm. in greatest spread of its radicular expansions and 9 mm. in height; the circular attachment area, which is 9 mm. in diameter and slightly concave, is covered with fine ridges radiating from the axial canal. These ridges increase both by interstitial additions and by bifurcation, some of the ridges bifurcating three times. Near the margin there are eight ridges in a space of 2 mm.

Another specimen (fig. 17), also shown natural size, 13 mm. in spread of its radicular expansions and 3 mm. high, is characterized by its deeply concave attachment area. This area is 5 mm. in diameter, 2 mm. deep and is ornamented with radiating ridges similar to those on the larger specimen.

The shell of an Orthoceras bears one attachment base whose radicular expansions have a spread of 10 mm., four bases with a spread of 8 mm., five bases with a spread of 6 mm., one base with spread of 5 mm., and several still smaller elevations which probably represent still younger stages of growth, though their preservation is not such as to permit their identification with certainty. Most of these attachment bases do not exceed 1 mm.

in height but two are from 2 to 2.5 mm. in height. The area for the attachment of the column is, in the case of the larger specimens, from 2 to 2.5 mm. in diameter. Four of these bases are shown in figure 15, magnified three and one-half diameters. The upper one is similar, except in size, to the largest specimen. (Fig. 16.) It measures 8 mm. in width, 2 mm. in height and the diameter of the surface for the attachment of the column is about 2 mm.

Eventually, no doubt, much will be learned regarding these attachment bases of the Heterocrinids, but with our present knowledge, we are unable to connect them with any of the columns or calyces which are associated with them.

Specimens.—Field Museum Nos. P.16882 and 16934.

Horizon and locality.—Lower Maquoketa shales at Clermont.

CRINOID STEMS OR COLUMNS

Associated with the above described crinoids are a quantity of stems. The majority of them are disarticulated columnals but there are also a number of stem fragments in which many columnals are attached. With our present knowledge, there seems to be no way of correlating these columnals with any of the calyces but there are a number of unusual forms among them which seem to be worth describing.

Crinoid column "A"

This type of stem is characterized by thin, flat columnals, more or less regularly alternating in thickness; serrated suture lines and a profoundly pentalobate axillary canal, each lobe being narrowly obovate in form. The collections contain many fragments of these stems ranging from a single columnal up to thirty or more columnals in length. In general appearance these stems resemble those of genera belonging to the order Flexibilia but several of these specimens have the lower row of plates of the base preserved and in all cases they are five in number and equal. As the base of flexible crinoids consists of three unequal plates, these can hardly be referred to that order. In the specimens of this type of columnals there are three kinds with characters distinct enough to be at least of specific importance.

CRINOID COLUMN "AA", Plate XXX, figs. 1, 2.

This stem is circular, gradually tapering from the top of the row of plates. The surface is smooth except for the serrated suture lines. The columnals are thin and irregularly alternating in thickness. The upper and lower surfaces of the columnals are flat and marked with radiating lines which are deep at the margins, giving crenulated edges to the columnals, and gradually becoming obsolete on approaching the axillary canal. The row of plates, probably infrabasals, are five in number, equal, and together they form a shallow cup with straight sides, somewhat expanding upward. The narrow obovate lobes of the canal are opposite the sutures between these plates, and are somewhat more slender than those in "Ab."

This column is known by four fragments ranging in length from about 7.0 mm. to 20.0 mm. and from 4.7 mm. to 7.6 mm. in diameter. The specimen figured measures: length 11 mm., diameter of upper columnal 7.0 mm., diameter of lower columnal 5.5 mm.

Field Museum P. 16862 and Walker Museum 27042.

Horizon and locality.—Upper Maquoketa shale at Patterson's Springs, near Brainard.

CRINOID COLUMN "AB", Plate XXX, figs. 8-11.

In general appearance this type of column is similar to the preceding; under the magnifier the surface is slightly granular but the most notable difference is in the form of the attached plates (probably infrabasals). These plates are 5.3 mm. wide and 2.3 mm. high along the median line, but only 0.5 mm. to 1 mm. high at the lateral sutures. The surface of these infrabasals curves strongly inward except at their tip where the curvature is distinctly outward. The largest column (fig. 8) has a diameter of 9.0 mm. Though only 5 mm. in length, it consists of ten columnals which show a tendency toward alternation in size. The sutures between the columnals zigzag more or less strongly up and down, about ten crenulations occupying a width of 5 mm. On the surface of the columnals these crenulations appear as lines radiate in direction, but extending inward for a short distance only, beyond which these lines disappear. The central part of the flat face of the columnals is sparsely and irregularly granulate or smooth. The axial canal is five-rayed, the individual rays being 0.8 mm. long, and very narrowly obovate in form. The rays coincide in position with the suture lines between the infrabasals. The longest column at hand is 21 mm. in length (fig. 11). It widens gradually from a diameter of 4.2 mm. at the base to 6 mm. at the top. Within this length the columnals alternate only slightly in height along the lower third of the column; along the middle third they alternate more distinctly; and along the upper third they alternate strongly.

This column is known by six fragments and thirteen single columnals. Field Museum P. 11265, Walker Museum 24702, and University of Iowa 3681, 3684.

Horizon and locality.—Lower Maquoketa shale at Clermont and Bloomfield.

Crinoid column "Ac", Plate XXX, figs. 3-7.

This column, while resembling the two preceding forms in having serrated suture lines and the profoundly lobed axial canal, differs from them in having a pustulose surface and in the size and shape of its columnals. In the upper part of the column (fig. 4) the columnals alternate, not only in thickness but the thicker one of the pair is also larger. Farther down in the column this arrangement changes (fig. 7) so that the columnals are in series of fours, consisting of a thick columnal larger than the others and three thin ones of the same size, the middle one of the three being thicker than the other two. The flat surfaces bear shallow rounded radiating furrows, which are visible near the margins only, forming a serrated suture line. The column is circular, the surface is evenly pustulose and the canal is profoundly pentalobate. (Fig. 6.)

The infrabasal plates of this species are intermediate in form between the two preceding species. These plates are five in number, equal, and form a shallow cup whose diameter does not exceed that of the top columnal; the median portion of each plate bends inward but does not curve outward again at the tip as is the case in "Ab."

Thus we find three distinct types of infrabasal plates; both of those from the Lower Maquoketa beds curve inward, although one also curves outward again at the tip of the plate, while the form from the Upper beds expands upward continuing the expansion of the column. The figures are natural size and the distinguishing characters are well shown.

This column is known by two fragments (figs. 3, 4) having the plates of the base of the calyx attached, one fragment farther down in the column (figs. 5, 7) consisting of eighteen columnals and about fifteen unattached columnals, ranging in diameter from 6 mm. to 13 mm.

Field Museum P.11264, University of Iowa 3677, Walker Museum 24703.

Horizon and locality.—Lower Maquoketa shales at Clermont.

Atactocrinus ? columnals, Plate XXX, figs. 20-31.

The most abundant forms of crinoid remains in these beds are the variously shaped, beadlike columnals which are illustrated. They appear to be congeneric with those described by Weller[5] from a similar horizon at Wilmington, Illinois, and doubtfully referred to the above genus. The surface ranges from granular to smooth in various parts of the columnal. The axillary canal is circular or nearly so.

These columnals may be divided into two kinds: (1) Those having flat upper and lower surfaces; these may be lozenge-shaped, such as the group in figure 31 or may have its height equal to its diameter, as the upper columnal in figure 20, which was attached to the base of the calyx, and whose upper surface shows the impression of the lower row of plates. (2) Those of the more beadlike forms which have a deep, almost hemispherical concavity on their upper and lower surfaces. These forms vary from very oblate spheroids to spheroids, spheres, cylinders with rounded corners, ellipsoids or spindle-shapes, etc. As the surface ornamentation of both these kinds is granular near the middle and smooth above and below, there seems to be little doubt that they all belong to the same genus; besides several columnals have been found in which the upper surface is nearly flat and the lower surface is concave, thus joining both kinds in the same column (see second columnal from the top of figure 20). Columnals as unlike as these are known to exist in the same column, as Springer[6] illustrates

5Contr. to Walker Museum Vol. 1, No. 10, p. 239, 1916.
6Crinoidea Flexibilia, Pl. V.

Mespilocrinus in which the columnals are lozenge-shaped in the upper part of the column and spindle-shaped farther down. The figured specimens are Walker Museum 24704, others are Field Museum P.18525, and University of Iowa 3679.

Horizon and locality.—Lower Maquoketa shale at Clermont and Bloomfield.

Acknowledgements

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WALKER MUSEUM,
THE UNIVERSITY OF CHICAGO.

PART TWO

BY AUGUST F. FOERSTE

CARABOCRINUS Billings

Dorsal cup consisting of eighteen plates, including five infrabasals, five basals, five radials, and three plates belonging to the anal series. Of the latter, the chief plate *X* is similar in shape and size to the radials, and is intercalated in the same row as the latter. The other two plates are intercalated in the same row as the basals; conjointly they exceed moderately in height any one of the basals, but they equal the latter in width. The upper one of the two plates, the radianal *RA*, is slightly shorter than the lower one, the supplementary plate *S*. (See also Plate XXXI, fig. 11.)

The radianal and supplementary plates are inserted between the posterior and right posterior basals, causing both of the latter to be moderately asymmetric in form. Along that part of the outline of these basals which is in contact with the supplementary plate, the curvature is slightly concave, usually more distinctly concave in case of the posterior basal than of the right posterior one. The other three basals are alike in form, all being symmetrical, hexagonal, and elongate. Four of the infrabasals are alike in form, but the fifth or left posterior infrabasal has an obliquely truncated tip, where it comes in contact with the lower left margin of the posterior basal. The left end of the truncated part of the left posterior basal always is more elevated than the right end.

The character of the ornamentation varies considerably in different species, and even in specimens belonging to the same species. In general, however, if any conspicuous ornamentation is present, this is likely to include more or less distinct ridges, most of which cross the sutures more or less at right angles, therefore at points distant from the corners. Each of the infrabasals has two ridges, one along each of the lateral margins. The left posterior infrabasal has in addition a third ridge, extending from the base toward the truncated tip; sometimes that ridge which extends along the right margin of this plate is much weaker than the neighboring ridge, on the right posterior infrabasal. That ridge of the posterior basal which extends toward the truncated tip of the left posterior infrabasal is single. All of the other basals, and also the supplementary plate in the same row, have two moderately diverging ridges extending downward, matching the lateral ridges of the infrabasal series. In the radials, only the two ridges extending downward are likely to be conspicuous. Similar ridges occur not infrequently on the anal plate *X*. The preceding description of the ornamenting ridges has been drawn chiefly from a species resembling *Carabocrinus vancortlandti* Billings, occurring on Goat Island, northeast of Little Current on Manitoulin Island, in strata corresponding to the Curdsville limestone in age. (Plate XXXI, fig. 11.) It will be found useful in identifying the isolated plates of the species of *Carabocrinus* occurring in the Lower Maquoketa of Iowa.

In the species of *Carabocrinus* occurring on Goat Island, the anal plate *X* is surmounted by three small plates, and a fourth small plate occurs over the left margin of the right posterior radial. All of these small plates increase in size successively from left to right; possibly a fifth small plate occurred over the left margin of the anal plate *X* itself, but this part of the specimen has been injured. This series of small plates supports the exterior side of that elevated part of the tegmen at the top of which the anus is located. (Plate XXXI, fig. 11.)

The facet on the radials, for the support of the arms, is long and narrow, with a relatively deep ambulacral sinus. (Text-figure 59 and Plate XXXI, fig. 11.) The ambulacral groove of the arms is correspondingly deep and narrow. On each side of the facet, the outer surface of the radials in many cases is channelled at right angles to its upper margin, the lower ends of these channels converging toward the median line of the plate. Each channel is bordered on each side by a narrow striation or elevation. The striations between each pair of grooves usually are connected by a sharp curve along their upper ends, but those bordering on the same groove either may be connected at their lower ends or may leave an open gap at this point. Bather states that these radio-oral folds probably are vestigial hydrospires as in *Hybocrinus*. (Echinoderma, p. 172, 1900.) These grooves and stereom folds appear to differ greatly in number and size in different individuals of the same species. Usually they are very few in number on the anal *X* plate, and may be absent altogether. Judging from some of the Goat Island specimens, that part of the radials which is grooved was covered by a thin membrane bearing numerous small granules. It is assumed that this membrane extended to the adjacent parts of the orals and connected up with the covering protecting the ambulacral grooves between the latter, and also with the ambulacral grooves traversing the arms lengthwise.

One of the Goat Island specimens exposes the ambulacral side of two of the dichotomously dividing arms. There are two series of quadrangular plates, one on each side of the median line of the ambulacral face of each arm or armlet (fig. 13, Pl. XXXI). Five of these quadrangular plates occupy a length of 2 mm., at a point where three of these quadrangular plates occupy the length of one arm plate. The quadrangular plates are slightly wider than long. Between the two median series of quadrangular plates and the lateral margins of the ambulacral side of the arms there are numerous smaller plates, more or less irregularly arranged; about two or three of these smaller plates occur in the width intervening between the ambulacral plates and the nearest part of the lateral margin of the arm plates. There is a tendency toward elongation of the smaller plates where they are adjacent to the median quadrangular plates, and a tendency toward a more circular outline where they are more distant from the latter; the circular plates usually are much smaller than the more elongate ones. Along the sutures between successive arm plates (fig. 14, Pl. XXXI) a depression is developed, extending from the ambulacral side of the arms along its lateral sides for fully or slightly more than half the dorso-ventral diameter of the arm along its lateral face. Along the lateral outline of the ambulacral face of the arms, these depressions along the sutures between the arm plates meet, but dorsally they become narrower, terminating with a strongly rounded outline. These depressions along the sutures are covered by minute plates, which probably studded the surface of some covering membrane. It is assumed that these lateral grooves with their covering of minute plates correspond to the recumbent arms or armlets of cystids. Since *Carabocrinus* is a crinoid, this structure might be called a recurrent or recumbent pinnule.

A closely similar structure is figured by Frank Springer in the case of a left anterior ray of *Cupulocrinus jewetti* (Billings), from the lower Trenton, at Kirkfield, Ontario. (Memoir Geol. Surv. Canada, No. 15P, pl. III, fig. 5b, 1911.) Here the minute plates covering the recurrent pinnules are drawn as regularly arranged, about five plates occupying a transverse section of the pinnules along the lateral margin of the ambulacral face of the ray, while eleven or twelve minute plates occur along the median line of the pinnule.

Mr. Springer describes the Kirkfield specimen as follows: "Here the left anterior ray is pulled out of position, so that we see the lateral face which is usually concealed by contact with the adjoining ray; it exposes a very peculiar surface marking—as of very small plates or the imprint of them—above the interbrachial plates, extending outward between transverse keels on the brachials, and obliterating the sutures."

Cupulocrinus is the most primitive genus among the Dendrocrinidae, in fact it is the most primitive genus of the entire order of Inadunata among the Crinoidea, as shown by Mr. Springer. There are good reasons for considering *Cupulocrinus* as close to the ancestral type of the two orders: Inadunata and Flexibilia. In his recent monograph on the Flexibilia Mr. Springer states that *Cupulocrinus* shows clearly an intermingling of the characters of the two orders, and that it is evident that it is a transition form.

Carabocrinus is another of the primitive Inadunata, belonging to the Cyathocrinidae. Similar recurrent pinnules may occur in other primitive crinoids among the Inadunata.

The arms of *Carabocrinus* branch dichotomously three or four times, the two inner arms after the second branching in some cases remaining undivided.

The column was relatively narrow, tapering distally, equalling 1.5 mm. in diameter at a distance of 20 mm. from the base of the calyx in the Goat Island specimens. In the latter the calyx has a height of 33 mm. and a width of 25 mm. The columnals alternate moderately in size and thickness.

For the Goat Island specimens (fig. 11, Pl. XXXI), here mentioned frequently in describing the general generic features of *Carabocrinus*, the name *Carabocrinus huronensis* is proposed. It differs from *Carabocrinus vancortlandti* Billings in its obconical rather than obovate outline, the basal part being distinctly more acute, the middle less inflated, and the top of the calyx less contracted than in that species. Moreover, the radiating ridges are much stronger, those of *Carabocrinus vancortlandti* being even smaller and more distant from each other than those of *Carabocrinus radiatus*.

Carabocrinus is chiefly a North American genus. The earliest known species, *Carabocrinus geometricus* Hudson, occurs in the Valcour limestone in the middle Chazyan of the Lake Champlain area of New York. *Carabocrinus dicyclicus* Sardeson occurs in the Decorah beds of Minnesota and Wisconsin. *Carabocrinus radiatus* Billings and *Carabocrinus vancortlandti* Billings are from the lower Trenton of Ontario. *Carabocrinus ovalis* Miller and Gurley is from the Curdsville member of the Trenton in Kentucky. *Carabocrinus* (?) *tuberculatus* Billings was described from the Vaurial (formerly Charleton) member of the Richmond formation on Anticosti Island. Ulrich cites an undescribed species of *Carabocrinus* from the Decorah beds, and two undescribed species from the Maquoketa (Richmond) of Minnesota (Geol. Minnesota, vol. III, pt. 2, p. cxxiii, 1897).

Recently a crinoid was described from the Wassalem limestone near Reval, in Esthonia, one of the Baltic States of Europe, under the name *Carabocrinus esthonus* Jaekel (Palaeontologische Zeitschrift, 3, pt. 1, 1918, p. 50, fig. 38). As far as may be determined from the figure it is remarkably similar in form, outline of plates, and ornamentation to *Carabocrinus ra-*

diatus, the genotype. The Wassalem limestone is regarded by Professor Raymond as of later age than those Trenton beds of Ontario which contain *Carabocrinus radiatus* and *Carabocrinus vancortlandti.* The presence of *Carabocrinus esthonus* in the Baltic area of Europe suggests the origin of this genus in northern North America and its migration into northern Europe. This agrees with the belief that the Decorah beds and the Curdsville member of the Trenton represent northern invasions, connecting with circumpolar areas.

CARABOCRINUS SLOCOMI sp. nov., Plate XXXI, figs. 1-10; Plate XXXII, figs. 1, 7-9, 12-14, 26-29, 19?, 20?.

Two fragments of calyces are at hand; in one fragment (figs. 1-3) the length of the radials is 5 mm., and that of the basals is 7.5 mm.; in the other fragment (figs. 4, 5) the length of the radials is 6 mm., that of the basals is 9.5 mm., and that of the infrabasals is 7 mm. The complete calyx of the second specimen is estimated to have had a height of 19 mm., with a width at the top of 12 or 13 mm. The general form of the dorsal cup is obovate, or almost inversely conical, with the radials more nearly erect.

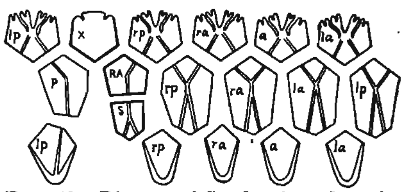


FIG. 59. Diagram of *Carabocrinus slocomi.*

One fragment (figs. 1-3) shows all of the plates belonging to the two upper circles of the dorsal cup, including the radials and basals. Of one of the radials only the upper half is visible. Of the anal plate *X* the right margin is concealed. The lower left margin of the posterior basal and the upper left part of the supplementary plate also are concealed. Each of the anterior and posterior pairs of basal plates is marked by four radiating ridges, of which two pass diagonally upward toward the middle of the sutures, and the other two pass downward with only a moderate amount of divergence. The lateral ridges are obsolete. That part of the posterior basal which is exposed does not show any distinct ridge in this specimen, but in the second fragment here described (figs. 4, 5) this posterior basal is marked by one ridge passing toward the suture separating it from the truncated infrabasal, and another ridge passing diagonally upward and toward the left to the middle of the suture separating this posterior basal from the left posterior radial. Each radial is marked by two ridges passing from the arm-facet diagonally downward toward the middle of the sutures beneath. The supplementary plate is marked by a median ridge which continues to the middle of the radianal and then turns toward the right, crossing the middle of the suture separating the radianal from the right posterior radial. The anal plate *X* shows a faint median elevation, but the radiating ridges are practically obsolete. The upper margin of the radials, on each side of the arm-facet, is marked by one or two, rarely three grooves. The left side of the upper margin of the anal plate *X* bears a single groove, the right side of this margin being concealed. In a free anal plate *X*, (fig. 7, Plate XXXII) from another specimen, the right side of this margin bears one groove, and the left side bears two. All of the ridges on the radial and basal plates rise but slightly above the elevation which they would have if the intercepted parts of the plates were flat, but met each other along straight lines at widely spreading angles, like facets of a crystal.

In the second fragment of a dorsal cup, here figured (figs 4, 5), the left side and lower part of the right posterior basal and all of the right anterior basal is preserved. The supplementary plate and the posterior basal are partly exposed. A considerable part of the left posterior basal is present, but no recognizable trace of the left anterior basal is exposed. Two of the radial plates are present, but neither is complete. Of the infrabasals, all except the left anterior one are present, well preserved, and fairly well exposed. The radiating ridges bordering the lateral margins of these infrabasals are replaced chiefly by broadly rounded marginal elevations which may become obsolete before reaching the upper margins of these plates or which may terminate there as narrow ridges, similar to those traversing the basals. The median line of the left posterior plate is traversed by a third ridge directed toward the upper truncating suture. One side of one of the radials bears only a single groove along its upper margin; and one side of a second radial bears two well defined grooves and one indistinct groove.

Numerous isolated plates are present. One infrabasal, 18 mm. long, suggests that the dorsal cup of this species may have attained a height of 50 mm. One right posterior basal, 21.5 mm. long, suggests that the dorsal cup to which it belonged was 43 mm. in height. An isolated radial, 15 mm. in height, but possibly belonging to another species, suggests that the dorsal cup to which it belonged was about 48 mm. in height.

The surface of the plates of the dorsal cup is covered by a shagreen of minute, microscopic granules, arranged more or less in lines, which may anastomose in a more or less reticular manner, but which tend to be more or less continuous, crossing the sutures approximately at a right angle. About twelve lines occupy a width of 1 mm. Within these narrow limits the lines curve irregularly and at minute distances from right to left and back again, but on a few plates they are remarkably straight. As in other crinoids, the individual plates tend to be divided into cuneate fields radiating from more or less central points, the theoretical lines of separation between these fields extending from these central points to the various angles on the margin of the plates. Most of the infrabasals have only two conspicuous fields, with the minute lines directed toward the two upper sutures; in case of the left posterior infrabasal there is a third field with minute lines directed toward the truncating suture. On the basals there are six fields. On the radials there are four fields. The minute ornamenting lines appear to be most irregular and most anastomosing on the infrabasals; on the basals they appear to be straighter and parallel to one another; on the radials they are in some cases distinctly straight and fairly conspicuous under a lens, appearing like sharp parallel lines, which, however, number twelve in a width of 1 mm., as in the case of the less regular lines on the basals. Apparently it is impossible to distinguish two species among the specimens at hand on the basis of differences shown by the more microscopic features presented by the surface of the plates of the dorsal cup. Distinctions based upon differences in the prominence of the radiating ridges or ribs will be dicussed later.

Locality and horizon.—Clermont, Iowa; in the lower part of the Maquoketa beds.

Figured specimens:

Holotye, No. 3686, in Museum of University of Iowa.
Allotype, in collection of A. G. Becker.
Isolated plates from Museum of University of Iowa, the collection of A. G. Becker, and the Field Columbian Museum at Chicago.

CARABOCRINUS SLOCOMI COSTATUS var. nov., Plate XXXII, figs. 15-18, 21-25, 30, 2-6?, 10?.

Carabocrinus slocomi is based chiefly on two fragments of dorsal cups, described in the preceding pages. Associated with these two fragments are numerous loose plates of dorsal cups, some of which closely agree with corresponding plates of the two fragments in the inconspicuous character of the radiate ribbing, while others are much more coarsely ribbed. A considerable number of coarsely ribbed infrabasals, including also truncated infrabasals, are present. There is also a fair number of coarsely ribbed radials. In these coarsely ribbed radials the number of grooves along their upper margins, on each side of the arm facet, tends to be greater, sometimes conspicuously so. Possibly these more coarsely ribbed plates are merely from older specimens, and do not even represent a distinct variety. Unfortunately no basal plates with equally conspicuous ribbing as the infrabasals and radials here discussed are known. Provisionally, the more coarsely ribbed forms are separated from the others as a variety.

LICHENOCRINUS MINUTUS sp. nov., Plate XXX, figs. 19 and 19.

Six specimens are at hand. The holotype (figure 19) is attached to the brachial valve of an entire specimen of *Strophomena fluctuosa occidentalis* Foerste. Three specimens are attached to the interior surface of a brachial valve of *Leptaena unicostata* Meek and Worthen. One specimen is attached to the exterior of a small fragment of a brachial valve of some Orthid.

The first of these specimens has a diameter of 2.2 mm. and is about one-third of a millimeter in height. The specimen may be described as consisting essentially of two circlets of plates, the individual plates differing in size, all plates more or less irregularly arranged, there being a tendency toward a third circlet of plates. The central part is depressed. At the center of the depression there is a minute attachment area, about one-fourth of a millimeter in diameter, to which the column supporting the calyx was attached. The specimen itself is the attachment disk of some crinoid, probably a Heterocrinid.

Of the three specimens on the brachial valve of *Leptaena unicostata,* the two larger ones have diameters of 3.3 mm., and the smallest of 2 mm. The plates are not very clearly defined, but here again the arrangement of plates is irregular and varies between two and three concentric rows in different parts of the attachment disc, the different rows not being differentiated.

The specimen on the exterior of the brachial valve of an orthoid shell has a maximum diameter of 4 mm., and a height of 1 mm. Here the tendency toward three concentric rows is very pronounced, but the plates still differ in size and are irregularly arranged. The surface of the disc itself is very irregular in its elevation; its center is deeply depressed.

A specimen from Walker Museum, attached to an infrabasal plate of *Carabocrinus,* is similar to the holotype in form and arrangement of plates. It is 2.3 mm. in diameter. In figure 18, this specimen is shown enlarged 3½ diameters, associated with *Corynotrypa elegantula.*

Type specimens.—The holotype is No. P. 16885; four paratypes are No. P. 18533, all in the Field Museum of Natural History; the other paratype is No. 27043 in Walker Museum.

Locality and horizon.—From Clermont, Iowa. In the Lower Maquoketa.

Remarks.—Dr. E. O. Ulrich cites *Lichenocrinus* from nearly all the divisions of the Platteville and Decorah and from the Prosser member of the Trenton. At the northern end of Goat Island, northeast of Little Current, Ontario, where the railroad crosses to Cloche Island, *Lichenocrinus* occurs eleven feet above the horizon containing *Carabocrinus vancortlandti* Billings, in the lower or Curdsville part of the Trenton formation. Schuchert cites *Lichenocrinus affinis,* a Richmond species, from among Mohawkian strata at the head of Frobisher Bay in the southern part of Baffin Land, in Arctic America.

Among described species of *Lichenocrinus,* all are from the Ohio-Indiana-Kentucky area, where they range from the Cynthiana formation to the top of the Richmond. It is probable that the geographical range of *Lichenocrinus* is much greater than here indicated, but that the difficulty of discriminating species from specimens usually consisting of the attachment bases alone is too great to invite their citation in faunal lists.

The occurrence of *Lichenocrinus* in the lower part of the Maquoketa suggests their eventual discovery in other faunas of northern origin.

Still farther north, at Swift Current, at the northern end of Cloche Island, *Lichenocrinus* occurs at the base of the Cloche Island member of the Black River, immediately above the very fine-grained white limestone forming the top of the Swift Current member. If the Cloche Island member be referred to the Decorah, and the Swift Current member to the upper Platteville of the Mississippi Valley, then the occurrence at Swift Current is of later date than the occurrences cited by Ulrich from the Platteville of Minnesota.

PLEUROCYSTITES Billings

The genus *Pleurocystites* belongs to the superfamily Glyptocystoidea, within which there is a systematic arrangement of the thecal plates. This arrangement varies more or less in different genera, but it is possible to imagine all the various arrangements as based on the same original scheme, variations from this scheme being due to gradual displacement of one or more of the plates. In the supposed archetype of this superfamily five transverse rows of plates are imagined to have been present, each row consisting of five plates. However, in all species known there are only four plates in the first or lower row, though one of these (No. 3) always has a truncated top and may be regarded as resulting from the fusion of two plates, which may be supposed to have been actually distinct in the archetype. The second plate on the left of the truncated plate (No. 1) always is connected across the suture with the plate resting on its upper left margin (No. 5) by trans-sutural folds of the stereom, occupying rhomboidal areas known as *pectinirhombs*. In the case of all pectinirhombs, half of one rhomb rests on one plate and the other half on the adjoining plate. In addition to the pectinirhomb on plates 1 and

5 there are other pectinirhombs variable in position in different genera. In the genus *Pleurocystites* there are two additional pectinirhombs, one connecting plates 14 and 10, and another connecting plates 11 and 12.

In the archetype of the Glyptocystoidea the anal opening is supposed to have been located between plates 7 and 8 of the second row and plate 13 of the third row. In the genus *Pleurocystites* the anal area has enlarged so enormously that it occupies almost all except the marginal part of one side of the theca. Plate 13 apparently has disappeared, whether by consolidation with some other plate or by actual disappearance is unknown, but the result of this disappearance is to bring plates 12 and 14 into direct contact with the anal area. Moreover, plates 7, 8, 12 and 14 have moved apart sufficiently to permit one corner of plates 6 and 9 almost to reach the anal area, while the upper margins of plates 2 and 3 form almost all of the lower border of this area. Other minor changes in the arrangement of plates have taken place. Plates 7 and 8 have moved below the level of plates 5, 6, and 9, which belong to the same transverse series. Plate 23, which belongs to the fifth transverse series, has lengthened basally, so that its lower part separates plates 17 and 18. The brachioles are supported, not on the upper margins of the fourth row of plates, but on plates 20, 22 and 17 of the fifth row, the number of brachioles being not five, but two. The anal area is covered by forty or more plates in addition to the smaller ones forming the anal protuberance which overlaps the lower right margin of the theca when viewed from the anal side.

Possibly plate 13 united with plate 14, but no proof for such a combination has been adduced. Since the brachials properly should be supported by the plates of the fourth transverse series, it would be interesting to learn which of the five arms of the archetype are retained in the genus *Pleurocystites*.

Pleurocystites belongs to the family Cheirocrinidae, in which the pectinirhombs on plates 14-15, and on plates 12-18, so characteristic of other families among the superfamily Glyptocystoidea, have been suppressed, and in which plate 13 has disappeared.

Pleurocystites differs from other genera belonging to the same family, namely *Cheirocrinus, Homocystis,* and *Glyptocystis,* in the restriction of the number of pectinirhombs, in the locations mentioned in the preceding lines.

The genus *Pleurocystites* appears to have originated in North America, from which it spread to Great Britain. In North America six species and two varieties have been described. Three of these species and one of the varieties occur in the Trenton formation at Ottawa, presumably in strata approximately at about the same horizon as those at Curdsville, in Kentucky, where another species is found. The Ottawa forms include *Pleurocystites squamosus* and its variety *robustus,* also *P. filitextus,* and *P. elegans,* all described by Billings. *Pleurocystites squamosus matutinus* Ruedemann occurs in the lower or Glen Falls division of the Trenton in New York. *Pleurocystites exornatus* Billings was described from the Trenton near Montreal, in Quebec. *Pleurocystites mercerensis* Miller and Gurley was described from the Curdsville limestone in central Kentucky. *Pleurocystites anticostiensis* Billings was described from the Vaurial (formerly Charleton) member of the Richmond on Anticosti Island. Of these species the genotype *P. squamosus,* its variety *robustus,* and *P. mercerensis* have anal areas covered by several hundred small plates, while those of *P. filitextus* and *P. exornatus* are covered by forty to fifty plates. Nothing is known of the anal areas of *P. elegans* or *P. anticostiensis.* Ulrich cites *P. squamosus* and two undescribed species from the Prosser member of the Trenton in Minnesota. (Geol. Minnesota, vol. 3, Pal., pt. 2, p. cxxiii, 1897.)

In Great Britain six species are known. *Pleurocystites rugeri* Salter is from the Caradoc of South Wales. *Pleurocystites anglicus* Jaekel is from the lower Ashgillian formation, a little younger than *P. rugeri* and a little older than the four species occurring in the lower Ashgillian of the Girvan area of Scotland, namely *Pleurocystites procerus* Bather, *P. quadratus* Bather, *P. gibbus* Bather, and *P. foriolus* Bather. Bather regards these British species as of later age than the Trenton species described from various parts of North America. The anal area of all British species except that of *P. procerus* is known; in all cases this area is covered by hundreds of small plates.

Recently Jaekel has proposed the new generic term *Dipleurocystis* for *Pleurocystites rugeri* and *P. anglicus,* on the basis of their having a larger anal area, with smaller plates, the pectinirhombs being narrowly elongated in a direction parallel to the rhomb-ridges or folds. In view of the numerous plates on the anal area of *P. squamosus,* the genotype, it appears difficult to draw the line between typical *Dipleurocystis* and typical *Pleurocystites,* while, if *P. filitextus* had been the genotype this division could more readily have been maintained. It is evident that Jaekel must have followed Haeckel in regarding *P. filitextus* as the genotype of *Pleurocystites.*

The direction of migration of *Pleurocystites* from the Ottawa area into the British Isles is unknown. At present none of the peculiar cystids or crinoids of the Ottawa area are known north of the head of Frobisher Bay, on Baffin Land. Here *Porocrinus shawi* Schuchert occurs in Mohawkian strata. *Porocrinus conicus* Billings is from the lower Trenton of the Ottawa area. *Porocrinus smithi* Grant is from the Trenton of Belleville, Ontario. *Porocrinus kentuckiensis* Miller and Gurley is from the Curdsville member of the Trenton in central Kentucky. *Porocrinus pentagonius* Meek and Worthen is of still older age, from the Platteville beds of Illinois. Ulrich cites *Porocrinus* from the Decorah of Minnesota. (Geol. Minnesota, vol. 3, Pal., Pt. 2, p. cxxiii, 1897.)

Recently Jaekel has referred the species formerly known as *Porocrinus radiatus* Beyrich, from the Ordovician of the St. Petersburg area, to a new genus *Perittocrinus,* with *Perittocrinus transitor* from the same area and horizon as a new species. Both species are from the Vaginatenkalk or Kunda formation, regarded as distinctly older than any part of the Mohawkian. From this genus *Perittocrinus* Jaekel regards *Porocrinus* as a possible derivative.

The general distribution of *Pleurocystites, Porocrinus, Perittocrinus,* 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.

In the description of species of *Pleurocystites* it has been found convenient to use certain terms not in common use. The *shoulders* are the angulate parts of the outline of the theca formed by plates 12 and 14 at the terminations of pectinirhombs. The *shoulder-angle* is the apical angle of the theca, formed by an extension of the upper lateral outlines of this theca, above the shoulders. The *lobes* are the lateral extensions of the theca below the level of the area of attachment of the theca to the column. The *thecal ratio* is found by dividing the greatest width of the theca by the height of that part of the theca which extends from the area of attachment to the column to the oral pole; in this measurement of the height, the vertical height of the lobes is not included. A similar ratio of width to height is worked out for plate 5 as the most valuable ratio furnished by any single plate, since this is the plate most frequently found well preserved in specimens otherwise injured.

The shape, prominence, and other features of the pectinirhombs often are characteristic. On the other hand, the surface ornamentation has been found extremely variable, even in specimens belonging to the same species, and is regarded as of least diagnostic value, unless supported by other differences.

The various species here described from the Lower Maquoketa of Iowa differ chiefly in their surface ornamentation, but other differences apparently also may be noted. The discrimination of these species would be regarded as more satisfactory if more specimens were at hand, but, for the present at least, the recognition of several species among the material at hand appears warranted.

1. PLEUROCYSTITES BECKERI sp. nov., Plate XXXIII, figs. 1, 6; Plate XXXIV, figs. 1A-D; Plate XXXI, fig. 12.

Type specimen.—Plate XXXIII, fig. 1; Plate XXXIV, figs. 1A, B, C, D); Plate XXXI, fig. 12.

Outline subquadrate, with a relatively obtuse apical or shoulder angle, equalling 95 degrees. Total height of theca above attachment area 34 mm., height up to shoulders 24 mm. The ratio of width of theca to height is 0.80, the width at plates 8 and 7 being 27 mm.; at plates 9 and 6 it is 26 mm.; and at plates 14 and 12 it is 25 mm. The lateral margins between plates 7 and 12 and between plates 8 and 14 are distinctly concave, though interrupted by angulations at plates 6 and 9. The lobes at the base of the theca descend about 2 mm. below the attachment area. The lobe formed by plates 2 and 7 is truncated at an angle of 50° with the vertical line. The lobe formed by plates 3 and 8 protrudes slightly beyond a rectangular outline. The angles at the shoulders and lobes are rounded, rather than abrupt. Plate 5 has a height of 11.7 mm. and a width of 11.9 mm. The pectinirhomb 1-5 is elliptical in outline, and is elongated in a direction parallel to the rhomb-folds. Pore-field only moderately smaller than the entire pectinirhomb, and also of elliptical form; containing fourteen folds. Pectinirhomb 14-10 is kite-shaped in outline, 11.5 mm. in length parallel to the rhomb-folds, 7 mm. in width at right angles to the folds, the corresponding measurements for the pore-field being 6 and 4.2 mm. The greater part of both the pectinirhomb and of the pore-field rests on plate 14. The distal margin of the pore-field on plate 14 is more broadly rounded than that on plate 10. There are twenty-one folds. The pectinirhomb on plates 11-12 also is kite-shaped, but with the narrow end pointing in the opposite direction. Its length and width are approximately 10 and 5 mm., the corresponding dimensions of the pore-field being 5.6 mm. and 2 mm. The greater part of the pore-field rests on plate 12. There are thirteen folds.

The ornamentation of the antanal side of the theca consists of rhombic fields of parallel ridges bisected by sutures passing between opposite angles of the rhombs, at right angles to the parallel ridges. Those halves of the fields which belong to the same plate form cuneate areas with their apices heading toward the same center, and with their bases formed by the various sides bounding the plate. The ornamenting parallel ridges cross the sutures approximately at right angles. On plate 5 about twelve or thirteen of these ridges occur in a width of 5 mm. On the anal side of plates 12, 7, 2, 3, 8, and 14 the surface ornamentation is granular, but there is a tendency on the part of these granules to be arranged in parallel lines.

The anal area, in conformity with the general outline of the theca, is large and quadrangular, with relatively straight lateral and basal sides but with a convex upper outline. The anal opening protrudes across the lower right angle of the theca, viewed from the anal side. Plates 2 and 3 appear to be represented by single plates, meeting along the median line of the theca along a suture 1.7 mm in height. Plates 12 and 14, on the contrary, meet along the median line at a suture only 0.5 mm. in height. From the anal side, the plates surrounding the anal area form a border ranging chiefly between 3 and 4 mm. in width. The field of the anal area is occupied by numerous small plates, chiefly hexagonal in outline and averaging about 0.8 mm. in diameter. It is estimated that about 800 of these small plates were present within this area. Only a few patches of these plates remain, but within these patches the individual plates are clearly defined.

The pectinirhombs rise with a convex curvature above the general surface of the theca. The pore-field on plates 14-10 rises only 0.5 to 0.7 mm. above this surface. The rim of the pore-field rises but slightly above this field, along some parts of the margin less than 0.1 mm.

Second specimen (Plate XXXIII, Fig. 6).—This second specimen resembles the type very closely, although certain differences can be observed. The chief of these consists in its outline. This outline, instead of being subquadratic, is more nearly ovate in form, the theca narrowing distinctly, from 20 mm. between plates 8 and 7 to 15 mm. between the tips of the pectinirhombs on plates 14 and 12; moreover, the apical or shoulder angle is distinctly more acute, equalling 80 degrees. Consequently, that part of the theca which is above the shoulders forms a greater part of the total height of the theca. The elevation of the pectinirhombs is relatively more abrupt and higher, equalling 1 mm. The pectinirhomb on plates 1-5 has ten folds, that on plates 14-10 has seventeen folds, and that on plates 11-12 has twelve folds. One of the brachioles is present, but it is slightly separated from the top of the theca so that its original point of attachment is uncertain. The surface ornamentation is as in the type. On the anal side the rim of plates bordering on the anal area also is broad, as in the type.

Locality and Horizon.—From Clermont, Iowa, in the lower part of the Maquoketa formation.

Type specimen.—In the collection of A. G. Becker.

Second specimen.—Specimen No. 16884, Field Museum of Natural History, Chicago, Illinois. Collected October, 1912, by A. W. Slocom.

Third specimen.—An isolated plate 5, numbered 17001 in the Field Museum of Natural History in Chicago, Illinois, is labelled as coming from Bloomfield, Iowa, in the lower part of the Maquoketa formation. Collected in October, 1912, by A. W. Slocom.

2. PLEUROCYSTITES SLOCOMI sp. nov., Plate XXXIII, fig. 5; Plate XXXIV, figs. 5A-D.

Outline of theca trapezoid ovate. The lower left margin of the theca slopes upward forming an angle of 25° with the horizontal, and the lower right margin slopes upward forming an angle of 35° with the horizontal. The sides of the theca are nearly straight but converge in an upward direction, from a width of 22.5 mm. between plates 8 and 7, to a width of 18 mm. between plates 14 and 12. The apical or shoulder angle is 85°. The shoulder and lobe angles are relatively abrupt. Total height of theca above attachment area about 31 mm.; height up to shoulders 21 or 22 mm. Ratio of broadest width of theca to height 0.72; the corresponding ratio for plate 5 is 0.95, the width being 10 mm., and the length 10.5 mm. The column apparently has been displaced slightly, having moved downward and toward the left. On the left side of the theca, viewed from the antanal side, the proximal part of plate 3 forms a lobe descending about the height of one columnal. Pectinirhombs as in the preceding species, but all are shorter in a direction parallel to the rhomb-folds, and all are more abruptly elevated above the general surface of the theca. Pectinirhomb 1-5 is 5 mm. long and 2.5 mm. wide; its pore-field being 2.5 mm. long and 1.7 mm. wide; the number of folds being eight. Pectinirhomb 14-10 is 8.5 mm. long, parallel to the rhomb-folds, and 7 mm. wide; its pore-field is 4 mm. long and almost 5 mm. wide; the number of folds being twenty-one. Pectinirhomb 11-12 is 8 mm. long and 4.5 mm. wide; its pore-field being 3 mm. long and almost 3 mm. wide; the number of folds being twelve. While the sides of the pectinirhombs rise more abruptly than in the preceding species, the border surrounding the pore-field is equally low in elevation .

The lower left part of the antanal side is margined by a thick, prominent border, a corresponding border margining the left side of the theca as far up as the basal part of plate 19. The lower right side of the theca appears to have a flat margin, and the border along the right margin is much less conspicuous than that on the left. The rhomb-ridges are more prominent, fewer in number, and more widely spaced. In the rhomb-field connecting the two upper pectinirhombs, the number of rhomb-ridges is nine in a width of 5 mm., a corresponding number occurring along the upper left margin of plate 5. In some rhomb-fields the rhomb-ridges are more widely spaced. The rhomb-fields are separated by conspicuous radiate ridges, passing from the umbos to the angles of the plates. The radiate ridges are regarded as diagnostic features, distinguishing this species from the preceding.

Of the column six segments or columnals remain. These narrow from a width of 6.8 mm. at the of the column to 3.8 mm. at its base, the distance being 8.5 mm. Within this distance the columnals all are of short height. The columnals probably were tuberculated, but their surface ornamentation is not well preserved.

Locality and horizon.—From Clermont, Iowa, in the lower part of the Maquoketa formation.

Type.—Specimen No. 16858, in the Field Museum of Natural History, Chicago, Illinois; collected October, 1912, by A. W. Slocom.

3. Pleurocystites clermontensis sp. nov., Plate XXXIII, fig. 7; Plate XXXIV, figs. 7A-D.

Outline ovate. The right margin of the specimen is missing, being cut away by the cleaning tools; apparently this part was not well preserved in the matrix. As far as may be judged from the specimen in its present state it was widest between plates 8 and 7, apparently 18 mm., narrowing toward plates 14 to 12, apparently to 15.5 mm.; the apical or shoulder angle apparently is somewhere near 75 degrees. On the left side of the theca, viewed from the antanal side, the proximal part of the lobe at the base of the theca descends the height of two of the prominent columnals below the attachment area. The corresponding part on the right is not preserved. The height of the theca from the attachment area to the oral pole is 22 mm.; the height to the left shoulder is about 15 mm. Apparently the ratio of width to height is about 0.82. The height of plate 5 is 7 mm. and its width is estimated at 6.5 mm., giving a corresponding ratio of 0.93. The lower left margin of the theca along plates 3 and 8 rises at an angle of about 45° above the horizontal, the angle at the middle of plate 8 being 95°. The angle at plate 14 appears rather broadly rounded. The pectinirhombs, as far as known, are similar to those of the two preceding species. They are fully as prominent as those of the second species here described, but the pore-fields are narrower and more elongate. Pectinirhomb 1-5 is 4 mm. long and 2.7 mm. wide; its pore-field is 2 mm. long and scarcely 1 mm. wide; the number of folds is four. Pectinirhomb 14-10 is 7 mm. long and 4 mm. wide; the number of folds is nine or ten. Pectinirhomb 11-12 is missing along with the remainder of the right margin of the theca.

In some respects the ornamentation of the antanal surface of this species resembles that of the preceding form. For instance, in the heavy border along the lower margin of plates 3 and 8; in the fairly heavy border along the left margin of the theca, and in the coarseness of the rhomb-ridges. In fact, the rhomb-ridges are even coarser, considering the size of the theca. Along the upper left margin of plate 5 there are six rhomb-ridges in a width of 2.5 mm., or at the same rate as eleven in a width of 5 mm., but toward the left of the rhomb-field intervening between the umbos of plates 1, 5 and 10 the rhomb-ridges are much more distant from each other. The most characteristic feature of this species, contrasted with the preceding one, is the absence of the radiate ridges which separate the rhomb-fields. Sufficient of the marginal border of the anal area is exposed to indicate that the exterior edge of this border is smooth, but that the remainder is closely tuberculated. The border is relatively broad.

Of the column a length of 15 mm. is preserved. In a length of 10 mm. this column narrows from a diameter of 4 mm. at the attachment area to 2.5 mm. at the seventh one of the more prominent columnals beneath this attachment area. Between these more prominent columnals, in alternate order, are six less prominent columnals whose upper and lower margins are covered or telescoped by the adjacent margins of the more prominent ones, so that in case of the upper columnals but little of the intermediate less conspicuous columnals is visible. Below the 10 mm. length of column there is an additional length of 5.5 mm., consisting of eight columnals, only slightly alternating in size, of which the lowest one has a diameter of 2 mm. Apparently the column diminishes abruptly in size near the theca, but gently at a greater distance, and the telescoping takes place only along the proximal part of the column. The columnals are tuberculated. The uppermost columnal has only a single transverse row of tubercles, but the broader columnals have additional tubercles above and below the more prominently elevated middle row.

Locality and horizon.—From Clermont, Iowa, in the lower part of the Maquoketa formation.

Type specimen.—No. 16858B, Field Museum of Natural History, collected by A. W. Slocom, in October, 1912.

4. Pleurocystites sp., Plate XXXIII, fig. 4.

Outline ovate triangular. Only the anal side of the theca is exposed. That part of the lower margin which is formed by plates 3 and 8 curves downward until it reaches the level of the second prominent columnal below the attachment area of the theca, and thence it curves upward as far as the corner formed by the middle of the margin of plate 8. This corner is nearly rectangular. From the corner formed by plate 8 to the shoulder which is located a little above the distal end of the pectinirhomb on plate 14, the lateral outline of the theca is straight. On the opposite side of the theca the outline is more curved. The lower margin of the theca here curves only slightly below the level of the uppermost prominent columnal, and thence curves upward along plates 2 and 7, the angulation on plate 7 being rounded. From this angulation to the shoulder on plate 12 the outline is straight, but the angulation at the shoulder is rounded so that the general appearance along the side of the specimen formed by plates 2, 7, 6, and 12 is that of convexity, while the outline along plates 8, 9, and 14 is straight, with an angular base. The outline of the theca above the shoulders is rounded to such an extent that it is difficult to state what the apical or shoulder angle is, but it is estimated at 85°. The height of the theca above its attachment area is 14.6 mm.; its height up to the shoulders is 11 mm. The width between plates 8 and 7 is 12 mm.; between the shoulders at plates 14 and 12 it is 7.5 mm.

At the apical part of the anal side, plates 12 and 14 at present are separated a distance of 1.5 mm., and appear never to have met. Plate 18 is very much reduced in size, while plate 19 is broad.

The interior faces of the plates forming the antanal side of the theca are marked by hexagonal outlines about 0.5 to 0.7 mm. in diameter, as though a trace of the plates covering the anal area remained here. If that is the case then the antanal area was covered by about 250 plates, possibly more.

Of the column a length of 15 mm. remains. In the upper 4.5 mm. of this length the column narrows abruptly from 2.6 mm. at the top to 1.8 mm. at the base of this length. This part includes six prominent columnals between which intermediate columnals occur whose lower and upper edges are more or less telescoped by the adjacent edges of the more prominent columnals. Below this level the character of the column changes abruptly. The next two columnals are each 0.3 mm. in length and 1.5 mm. in width. This is followed in a distal direction by columnals 0.7, 0.8, 1.2, 1.3, 1.5, 1.7, and 2 mm. in length, of which the last is scarcely 1 mm. in diameter; all of these longer columnals probably are produced by the coalescence of two or more columnals, as far as may be learned by the presence of a slight transverse annulation at or a little above mid-length.

Locality and horizon.—From Dover township in Fayette county, the next township west of Clermont township, in which Clermont, Iowa, is located. In the Middle Maquoketa.

Figured specimen.—Collected by A. G. Becker.

5. PLEUROCYSTITES MULTISTRIATUS sp. nov., Plate XXXIII, figs. 2, 3; Plate XXXIV, figs. 2A-C. (*Description by E. O. Ulrich and Edwin Kirk.*)

This is stratigraphically one of the latest known species of *Pleurocystites,* the possible exception being *P. anticostiensis,* the exact stratigraphic position of which is uncertain, to say the least. The species is well marked and is represented by a fairly well preserved individual. The upper two ranges of plates, and the marginal plates on the left side are missing for the most part, but the nature of the theca is such that a very exact reproduction of the missing plates is possible.

As restored, the theca has a length of 36.8 mm. and a breadth of 27.2 mm. The greatest breadth lies in the plane passing through the angles formed by plates 7 and 8. The base of the theca on either side of the stem is flat for a short distance. The sides then turn abruptly upward, at a comparatively high angle, the change in direction taking place within plates 2 and 3. The restoration of the specimen may err in that the lower left-hand part of the theca is given as approximately symmetrical with respect to the opposite side. It is quite possible that the asymmetry developed on this side as the result of the presence of the anal structure is quite marked, and that this part of the theca should be considerably produced. This direction is maintained until the upper portions of plates 7 and 8 are reached. Here the sides make another abrupt angle. The sides now converge very slightly to the middle of plates 12 and 14, where the rate of convergence is abruptly accelerated. As is suggested by the lateral depressions and the intermediate flattened area, in the extreme distal portion of the theca, it seems probable that the theca ended in a blunt, rather square nose, as is indicated in the figure. The theca is more elevated and has greater relief than any other species of *Pleurocystites* known. The center of the theca is highly elevated while within the elevated area itself, and lying between the three rhombs, is a somewhat depressed area. The slope to the margin from this elevated area is quite abrupt on all sides except toward the anterior and posterior ends. Just anterior to the angles formed by plates 12 and 14, and just posterior to the angles formed by plates 7 and 8 are sharply defined lateral depressions. A lateral view of the theca, Plate XXXIII, figure 3, shows a remarkable flexure in the marginal plates.

The ornamentation of this species consists of a complicated series of parallel striae. From each face, and perpendicular to it, numerous striae run back toward the center of the plate. The sets of lines from adjoining faces intercept one another along lines running from each angle to a common center. This common center, in no case where it was observed, coincides with the center of the plate. On plates bearing rhombs, the point is at the apex of the rhomb. On other plates, so far as observed, the point, as mentioned above, is excentric, and is located in the portion of the plate nearest the margin of the theca.

Plates 1 and 4 are of moderate size. They have a common suture 3.8 mm. in height, and plate 1 has a maximum length of 10.4 mm. Plates 2 and 3 are of average size but are relatively inconspicuous, owing to the fact that they form the bottom of the posterior, lateral depressions that have been noted above. Plate 7 enters to a considerable extent into the composition of the dorsal side. On the ventral surface, plate 7 meets plate 11 at about the level of the top of plate 5. Plate 5 is broader than long, the measurements being 13.4 mm. by 12.6 mm. The lateral faces of this plate are convex, and the upper pair of faces are slightly concave. The lower faces are straight. Plate 6 is notable chiefly as making the crest of the flexure that is such a characteristic feature of the margin of this species. As is usual among the species of *Pleurocystites,* plate 11 is appreciably smaller than plate 10. The higher ranges of plates are not preserved. A notable feature about the plates as a whole, is their unusual thickness and solidity. The plates of the ventral surface are unknown, except for a few isolated patches along the margins. These patches are made up of very small plates.

Rhomb 1-5 is elongate oval, the long axis, which lies perpendicular to the suture, measuring 5.6 mm. in length, while the short axis gives a measurement of 2.5 mm. There are fifteen slits in this rhomb. The raised area about the rhomb is diamond-shaped, with the long axis coinciding with that of the rhomb itself. As in other species, the portion of the rhomb lying on plate 1 is greater than that on plate 5. By measurement, the portion on plate 5 has a length of 2.3 mm. and on plate 1 of 3.3 mm. Rhomb 11-12 is irregular eggshaped in outline, having a measurement of 5.7 mm. at right angles to the suture by 3.6 mm. along the suture. The rhomb has eighteen slits. In the long axis of this rhomb 3.9 mm. lie within plate 12 and 1.8 mm. within plate 11. The raised border surrounding the rhomb is irregular in outline, and variable in thickness, the general outline, however, being elongate kite-shaped. Of rhomb 10-14 we have preserved only that part lying on plate 10. This gives a length of 5.4 mm. along the suture and a measurement of 3 mm. perpendicular to the suture for that portion preserved. There are twenty-six slits in the rhomb. The raised rim surrounding the rhomb is of moderate thickness, and seems to have been fairly regular in outline. It is probable that the rhombiferous area was nearly square, resembling the corresponding area of *P. angularis*.

None of the openings is known, owing to the poor preservation of the ventral surface.

The stem, from a measurement made from the proximal nodal, has a diameter of 6.6 mm. The nodals are marked by low, broad, smoothly-rounded and closely-set transverse ridges. Each of these ridges seems to have been formed by the confluence of two marginal tubercles. The ornamentation of the column is essentially similar to that of *P. anticostiensis*. The column so far as observed is composed of alternating narrow and wide ossicles.

This species is not closely comparable with any other described *Pleurocystites*. From *P. anticostiensis,* the only species having approximately the same stratigraphic position, it differs in possessing a marked linear ornamentation, and in the character of the rhombs. It is unquestionably the most strongly ornamented species of the genus yet described.

Horizon and locality.—Lower Maquoketa, two miles northwest of Clermont, Iowa.

Type.—The type and only known specimen is in the United States National Museum.

Pleurocystites multistriatus Ulrich and Kirk

Plate XXXIII, fig. 2. Dorsal view of type specimen x 3/2.
Plate XXXIII, fig. 3. Lateral view of type specimen x 3/2.
Plate XXXIV, fig. 2A. Lower half of rhomb 10-14, x 3.
Plate XXXIV, fig. 2B. Rhomb 11-12, x 3.
Plate XXXIV, fig. 2C. Rhomb 1-5, x 3.

Explanation of Plate XXIX.

Dendrocrinus kayi Slocom, page 335.

Figs. 1-3. Anterior, posterior and lateral views of the holotype. x 3/2.

Fig. 4. A column probably of this species. x 3/2. Coll. of A. G. Becker.

Ectenocrinus raymondi Slocom, page 337.

Figs. 5-7. Right lateral, posterior and left lateral views of the holotype. x 5/4. Walker Museum 24701.

Figs. 8, 9. Dorsal and lateral views of a portion of the arms, showing transverse grooves, pinnules and form of the arm plates. Greatly enlarged.

Archaeocrinus obconicus Slocom, page 328

Figs. 10, 11. Lateral and posterior view of the holotype. Natural size. Field Museum P.17106.

Fig. 12. Basal view of the allotype. Natural size.

Fig. 13. Lateral view of the allotype showing ornamentation of the plates. Enlarged 3 1/2 diameters. Field Museum P.11263.

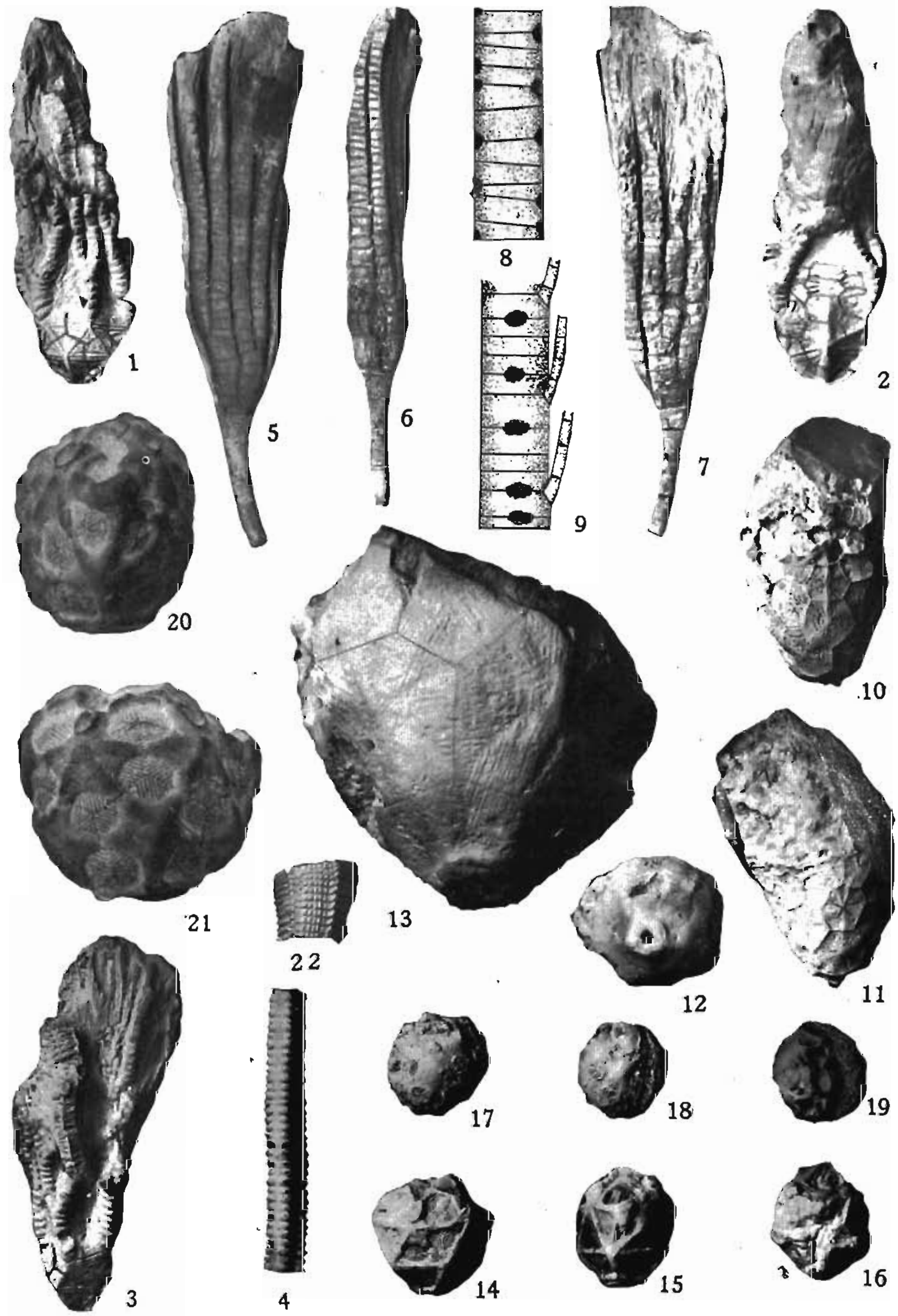
Porocrinus fayettensis Slocom, page 333.

Figs. 14-16. Lateral, posterior and ventral views of the holotype. x 3/2. Walker Museum 24700.

Figs. 17-19. Lateral, posterior and ventral views of the allotype. x 3/2. Field Museum P. 16841.

Figs. 20, 21. Lateral and posterior views of one of the paratypes. x 4. Field Museum P.11262.

Fig. 22. Fragment of a very large column. x 3/2. Field Museum P.11135.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Explanation of Plate XXX.

Crinoid Column "AA", page 341.

Figs. 1, 2. Lateral and end views x 3/2. Walker Museum 27042.

Crinoid Column "AC", page 342.

Fig. 3. Interior of basal cup.

Fig. 4. Side view of the upper part of the column showing the alternating columnals and the basal plates, three of which are attached. University of Iowa 3677.

Fig. 5. View of section of column showing form of columnals lower down on the column.

Fig. 6. End view showing radiating lines and shape of axial canal.

Fig. 7. View of the opposite side of fig. 5 showing the transition from fig. 4 to fig. 5. Field Museum 11264. Figures 3 to 7 natural size.

Crinoid Column "AB", page 341.

Fig. 8. Side view of the largest specimen with infrabasal plates. Fig. 11 side view of longest specimen. x 3/2. Field Museum P. 11265.

Fig. 9. Interior of basal cup. x 3/2. University of Iowa 3684.

Fig. 10. End view showing axial canal, radiating lines and granules. x 3/2. Walker Museum 24702.

Maquoketocrinus ornatus Slocom, page 330.

Figs. 12, 13. Basal and lateral views of the holotype. Field Museum P. 16840. Enlarged 3 1-2 diameters.

Porocrinus fayettensis Slocom, page 333.

Fig. 14. Edge of a plate enlarged 16 diameters, showing the folding at the angles. University of Iowa 3676. Photo by Dr. H. E. Wilson.

Heterocrinus?, page 339.

Fig. 15. Attachment bases on Orthoceras. Field Museum P. 16934. Enlarged 3 1/2 diameters.

Figs. 16, 17. Large bases. Natural size. Field Museum P. 16882.

Lichenocrinus minutus Foerste, page 353.

Fig. 18. One of the paratypes attached to a plate of Cara-

bocrinus, with *Corynotrypa elegantula*. Enlarged 3 1/2 diameters. Walker Museum No. 27043.

Fig. 19. The Holotype, attached to a *Strophomena fluctuosa* Foerste. Enlarged 2 diameters. Field Museum P. 16885.

Atactocrinus? columnals, page 343.

Fig. 20. A line of eight columnals of average size, showing variation in form.

Fig. 21. End view of the upper columnal in fig. 20.

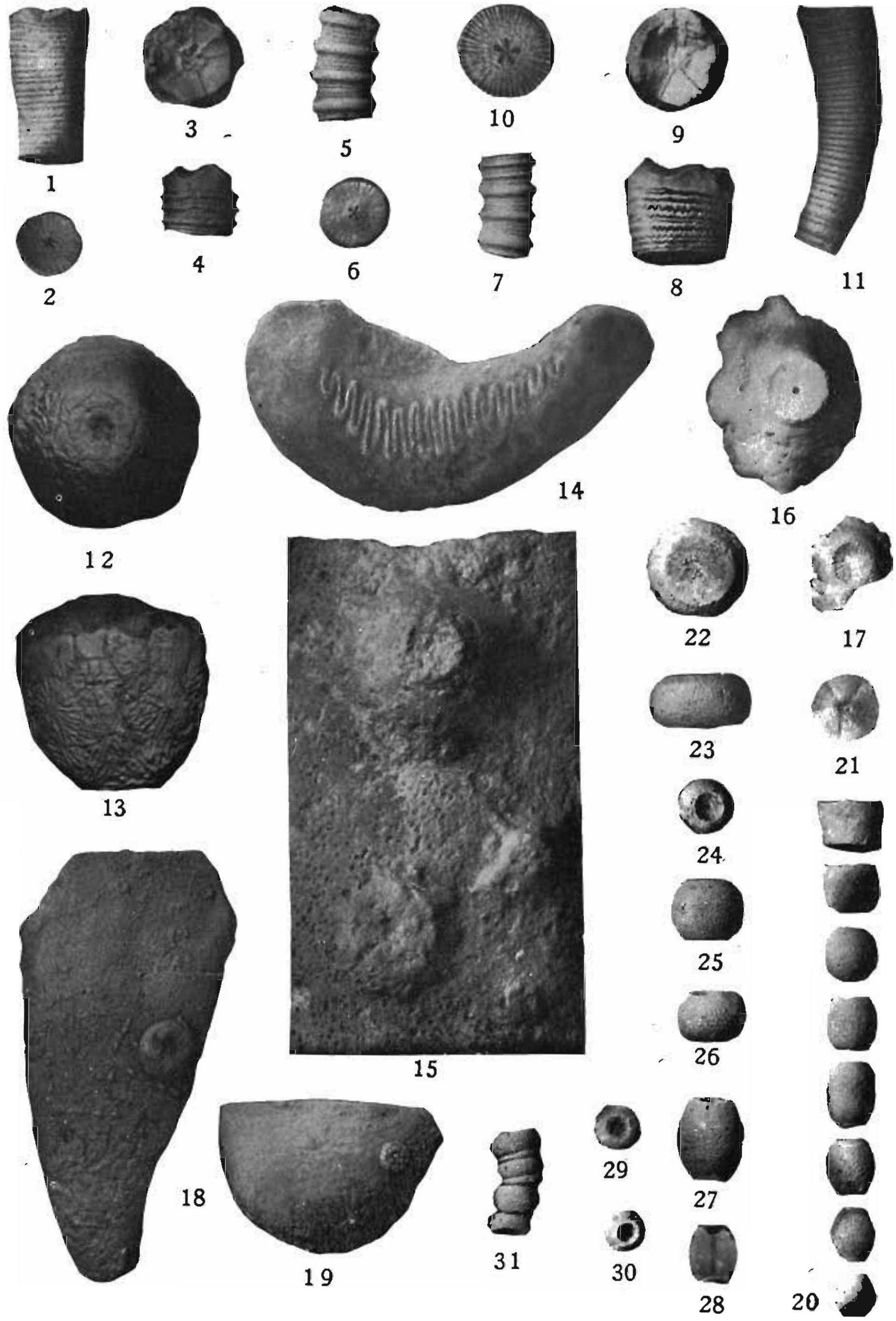
Figs. 22, 23. End and side views of the most oblate columnal observed.

Figs. 24-27. End and side views of some of the larger columnals.

Fig. 28. Longitudinal section of a columnal.

Figs. 29,30. End views of average columnals.

Fig. 31. Fragment of a column, consisting of 6 lozenge-shaped columnals, attached. All Walker Museum 24704. Enlarged 1 1/2 diameters.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Explanation of Plate XXXI.

Carabocrinus slocomi Foerste, page 350.

Figs. 1-3. Three views of a fragment retaining the basals and radials. From Clermont, Iowa; in Lower Maquoketa. Holotype; Museum of University of Iowa. No. 3686. Magnified 3 diameters.

Figs. 6-8. Diagrams of the same figures, designating the plates.

Figs. 4-5. Two views of a fragment retaining the infrabasals, and also parts of the basal and radial series of plates. From Clermont, Iowa; in Lower Maquoketa. Allotype; in collection of A. G. Becker.

Figs. 9-10. Diagrams of the same figures, designating the plates.

Carabocrinus huronensis Foerste, page 345.

Fig. 11. Diagram of plates of the type specimen. From the northern edge of Goat Island, directly east of the railroad bridge; in the lower part of the Trenton formation. In collection of A. F. Foerste.

Pleurocystites beckeri Foerste, page 359.

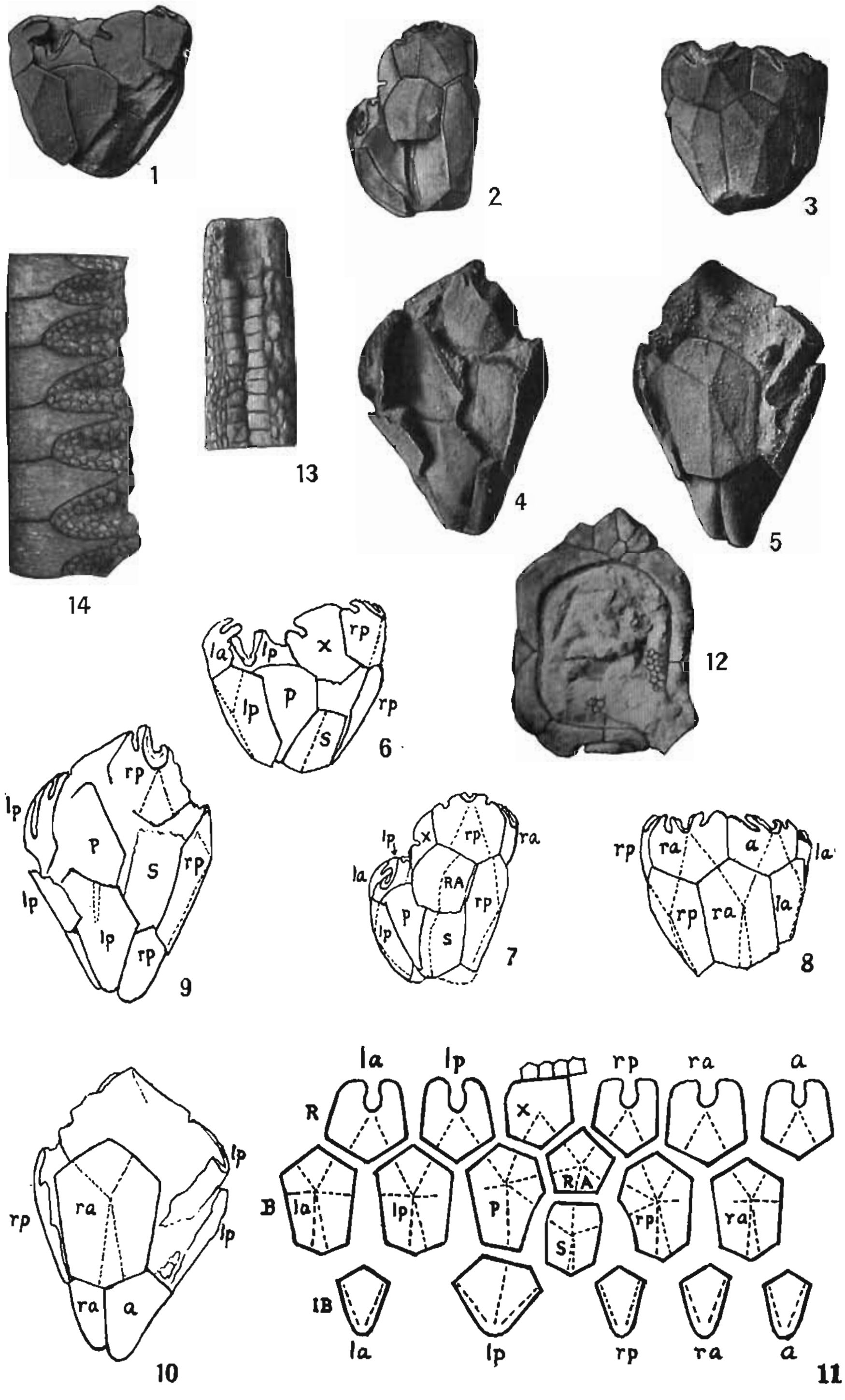
Fig 12. Anal side, showing traces of the minute plates covering the anal area. Type specimen. Anal side of fig. 1 on Plate XXXIII.

Carabocrinus huronensis Foerste, pages 347, 349.

Fig. 13. Ambulacral side of one of the arms.

Fig. 14. Lateral side of another arm of the same specimen. Both figures magnified 6 diameters. From the northern edge of Goat Island, directly east of the railroad bridge; in the lower part of the Trenton formation. In collection of A. F. Foerste.

In the diagrams of *Carabocrinus,* the following abbreviations are used; a, anterior; p. posterior; r, right; l, left; *X,* anal *X* plate; RA, radianal plate; S, supplementary plate; R, radial series of plates; B, basal series of plates; IB, infra-basal series of plates; the broken lines indicate the location and direction of the radiating ribs.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Explanation of Plate XXXII.

Carabocrinus slocomi Foerste, page 350.

Figs. 1, 7, 8, 9, 11, 12, 13, 14. *Carabocrinus slocomi* Foerste. Possibly figures 19, 20, also belong here.

Carabocrinus slocomi costatus Foerste, page 353.

Figs. 15-18, 21-25. *Carabocrinus slocomi costatus* Foerste. The figures cited above are those of the types of the variety. Possibly figures 2-6, 10, also belong here.

Figs. 1-5. Radials, showing facets for articulation with brachials, and the bordered grooves along their upper margins. Plates 2, 3 and 4 are imperfect along their lateral and lower margins.

Fig. 6. Another plate from the same row as the radial series, but without a deep ambulacral notch; possibly an anal *X* plate. Basal part broken off.

Fig. 7. An anal *X* plate.

Fig. 8. A radianal.

Fig. 9. A basal; either right or left anterior, or left posterior.

Fig. 10. A right posterior basal, broken at the top.

Figs. 11-19. Infrabasals; either one of the three anterior basals, or the right posterior one.

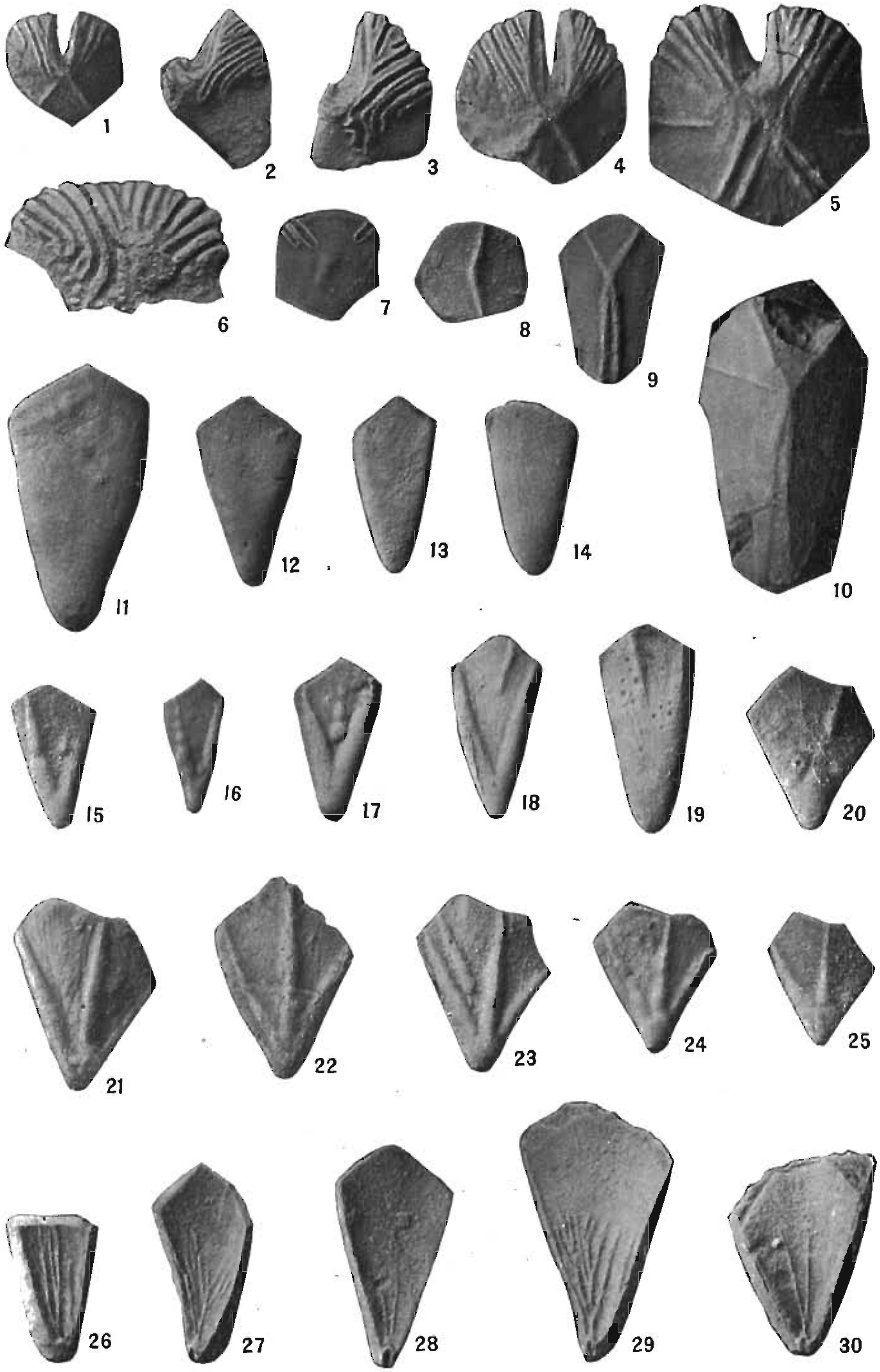
Figs. 20-25. Left posterior infrabasals. 22 is broken at the top.

Figs. 26-30. Vascular markings on the inner surface of the infrabasals. 26, 30 are broken at the top.

All of these plates were found near Clermont, Iowa, in the Lower Maquoketa. All figures magnified 3 diameters. 7, 8, 9, 10 belong to the Field Columbian Museum at Chicago, Illinois, and are numbered 7-9=P.18531; 10=P.18532.

2, 3, 6, 15, 16, 20, 23, 24, 25, 26, 30, belong to the Museum of the University of Iowa and are numbered 3687, 3688 and 3689.

1, 4, 5, 11, 12, 13, 14, 17, 18, 19, 21, 22, 27, 28, 29 belong to the collection of A. G. Becker.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Explanation of Plate XXXIII.

Fig. 1. Pleurocystites beckeri Foerste, page 359.

Lower left margin broken; outline restored there. Magnified 2 diameters. From Clermont, Iowa; in the Lower Maquoketa. From the collection of A. G. Becker. Holotype. The anal side of this specimen is figured on plate XXXI (fig. 12). The plate diagram of the theca and the pectinirhombs are figured on plate XXXIV (figs. 1 A-D).

Figs. 2, 3. Pleurocystites multistriatus Ulrich and Kirk, page 366.

The upper two ranges of plates and the left side of the theca are missing for the most part. Holotype. 2, antanal view, magnified 3/2 diameters; 3, lateral view, magnified 3/2 diameters. The pectinirhombs are figured on plate XXXIV (figs. 2A-C). From two miles northwest of Clermont, Iowa, in the Lower Maquoketa. From the U. S. National Museum.

Fig. 4. Pleurocystites sp., page 365.

Anal side of a specimen, not showing any of the plates covering the anal area. Magnified 2 diameters. From Dover township in Fayette county, Iowa; in the Middle Maquoketa. From the collection of A. G. Becker.

Fig. 5. Pleurocystites slocomi Foerste, page 362.

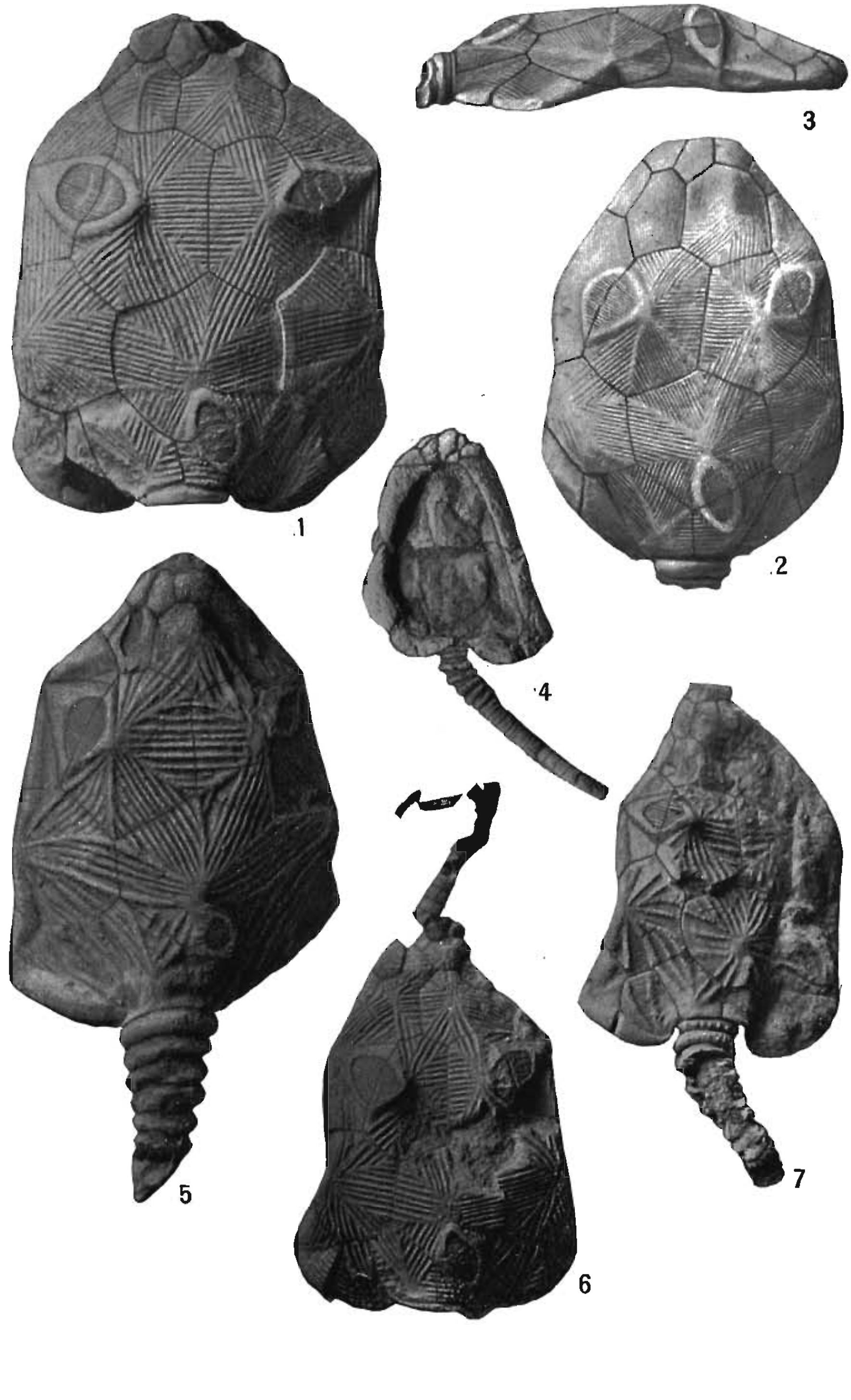
Antanal side of theca, with part of one of the brachioles. well preserved only along the central parts of the specimen. Magnified 2 diameters. From Clermont, Iowa; in the Lower Maquoketa. From Field Museum of Natural History; No. P.18529. The plate diagram of the theca and the pectinirhombs are figured on plate XXXIV (figs. 5A-D).

Fig. 6. Pleurocystites beckeri Foerste, page 359.

Antanal side of theca, with part of one of the brachioles. Magnified 2 diameters. From Clermont, Iowa, in the Lower Maquoketa. From Field Museum of Natural History; No. 16884.

Fig. 7. Pleurocystites clermontensis Foerste, page 363.

Antanal side of theca, with all of the right margin indistinctly preserved. Magnified 2 diameters. From Clermont, Iowa, in the Lower Maquoketa. From Field Museum of Natural History; No. 16858. The plate diagram of the theca and two of the pectinirhombs are figured on plate XXXIV (figs. 7A, C, D).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Explanation of Plate XXXIV.

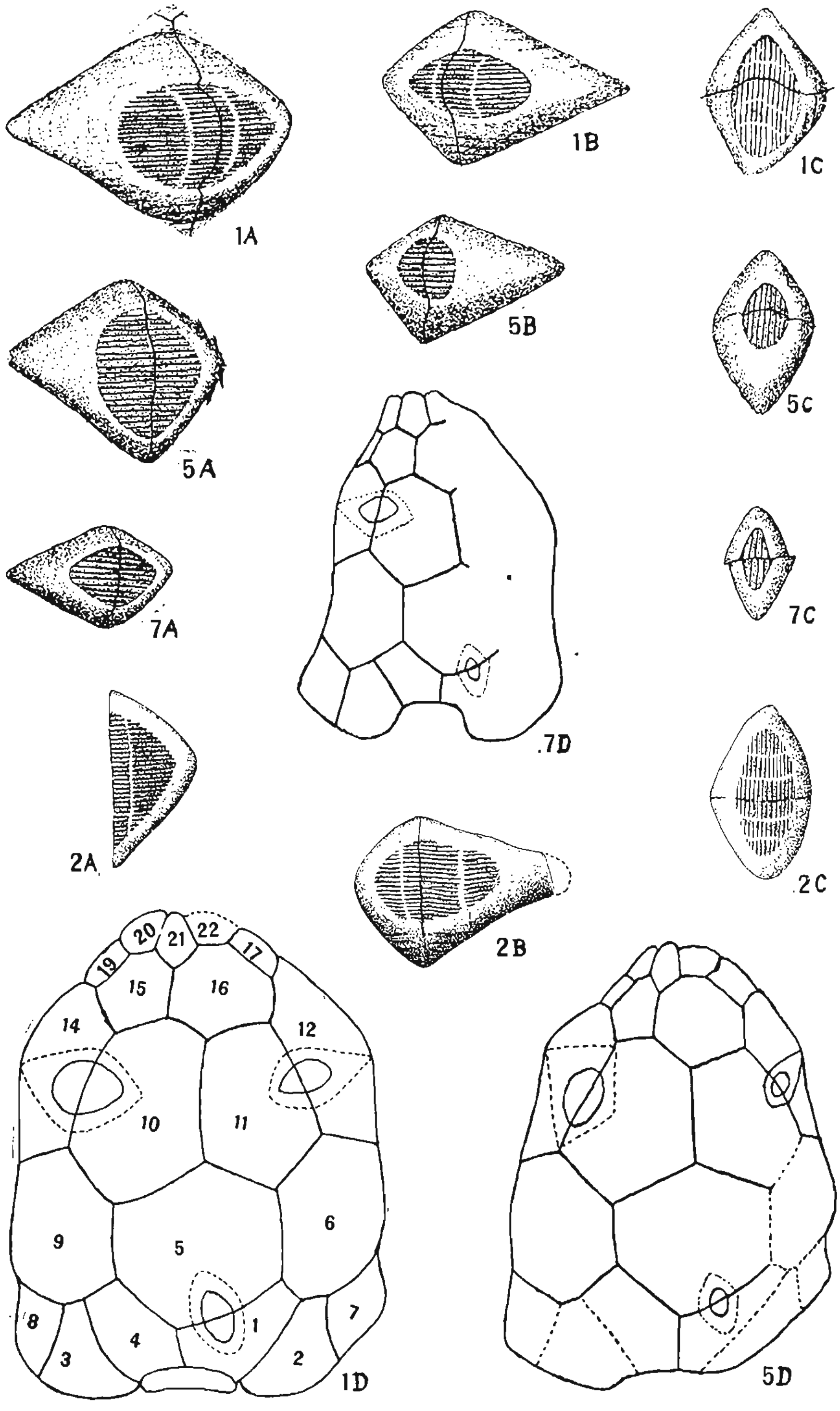
Fig. 1. Pleurocystites beckeri Foerste, page 359.

Fig. 2. Pleurocystites multistriatus Ulrich and Kirk, page 366.

Fig. 5. Pleurocystites slocomi Foerste, page 362.

Fig. 7. Pleurocystites clermontensis Foerste, page 363.

The numbers of the figures on this plate correspond to those used on plate XXXIII. The pectinirhombs are magnified about 3.7 diameters. In all figures A represents pectinirhomb 14-10; B represents pectinirhomb 11-12, and C represents pectinirhomb 1-5. In figure 1D the plates of the antanal side are numbered in accordance with the system used by Dr. F. A. Bather of the British Museum of Natural History.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ECHINODERMS OF THE IOWA DEVONIAN

BY

A. O. THOMAS

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ECHINODERMS OF THE IOWA DEVONIAN

Introduction

It has been nearly eighty-five years since David Dale Owen collected and reported the first echinoderm remains from the Devonian rocks of Iowa. Since that time additional contributions to our knowledge of this interesting group of animals have been made by almost a score of students of the life remains found in these rocks within the state. The published accounts of their findings are widely scattered and in most cases are available only to those who have access to large libraries stocked with various state and government reports.

It is the purpose of this paper to bring together this scattered literature, thus better to preserve the work of the pioneer scientists, to amplify their observations in the light of later and fuller discoveries, and to add such new material as remained undescribed in the collections of the late Dr. Samuel Calvin together with a number of new species secured by the writer during his study of the Iowa Devonian for the State Geological Survey, and finally many fine species have been freely contributed for study by several people, acknowledgment of which is made in the body of the report.

The species described are distributed over twenty-two genera and belong to forty-three species and two varieties. Of the genera, two are new and seven others have not been previously reported from the Devonian of the state. Twenty-four of the species and the two varieties are new. All have been illustrated in a series of twenty plates and a number of text figures. Illustrations of a few species occurring outside the state have been introduced for comparison. In the classification, Zittel's Textbook of Paleontology, second edition, has been followed in the main. The writings of Wachsmuth and Springer on the camerate crinoids, of Springer on the flexible crinoids, and of Jackson on the echinoids have been freely consulted. Bather's paper on the Triassic Echinoderms of Bakony has also proved very helpful in interpreting the dissociated echinoid material. Genera which are new or peculiar to our area have been more or less fully described. The museum location of types is cited in all cases where it is known.

Previous Work on the Echinoderms of the Area

As intimated above it was Dr. David Dale Owen, commissioned as "Principal Agent to explore the Mineral Lands of the United States", who first observed echinoderm remains in the Devonian terrane of the Iowa territory. This was in 1839. In the revised report published in 1844, on page 32, is a statement that "About three miles west of Rockingham, in Iowa, occur strata abounding in *Entrochites* and *Reteporae,--*". On plate xi are illustrated two weathered slabs which "display on their surface a variety of *Entrochites* and *Reteporae;* also, a Tentaculites and a new coral *Cyathopora Iowensis,* O." Owen was of the opinion that the rock was Carboniferous limestone although he "did not obtain unequivocal evidence." The slabs illustrated can be duplicated at many points in the Cedar Valley limestone all the way from Muscatine county, where Owen collected his, to Johnson county and on north to Bremer county. The fossils on Owen's slabs are stem segments presumably of *Megistocrinus;* the bryozoa which he thought to be bits of the fronds of *Archimedes* are parts of a *Fenestella,* of *Cystodictya hamiltonensis* Ulrich, and of others; the *Tentaculites* is *T. hoyti* White; while the coral is now referred to *Cladopora iowensis* (Owen). In his 1852 report, page 85, Owen made the correction and referred the beds to the Devonian. In the latter report this shrewd observer mentions finding *Hexacrinus* and *Olivanites* (*Nucleocrinus*) at Davenport and below Rockingham, respectively. These are the first echinoderm genera identified from our Devonian rocks and it is interesting to note that these localities furnished the types of new species in each genus as will be noted later in this paper.

In 1858, James Hall's well known report on the Geology of Iowa appeared in two parts. This contains the results of the investigations made by him and his staff during portions of the years 1855-1857. It is not necessary here to dwell on his interpretation or mapping of the Devonian of the state, suffice to say that in its larger features the work is surprisingly accurate. He emphasizes the Encrinal limestone along the river south of Davenport (pp. 86, 87) and notes a species of *Pentremites* and numerous fragments of crinoids and crinoidal columns in the vicinity of (New) Buffalo. In the paleontological part of the report he described and illustrated one new blastoid, *Codaster subtruncatus,* and three new crinoids, *Megistocrinus latus, Taxocrinus interscapularis,* and *Synbathocrinus matutinus,* all from the beds about Buffalo. Again in 1861 we find Hall including a crinoid from Iowa City with other similar crinoids from Milwaukee, Wisconsin, and describing them under the name *Melocrinites nodosus.* In passing it may be noted that Hall contributed much to the early knowledge of the Burlington crinoids of Iowa and his descriptions, illustrations, and diagrams of these prove him to be a keen observer and a clear writer.

One of the most enthusiastic students of paleontology, an indefatigable collector, and one who was unusually careful in the preparation and preservation of his specimens was the Rev. W. H. Barris. Trained for the ministry but with a strong leaning toward natural history he was called from his first charge at Brockport, New York, to become rector of Trinity Church at Iowa City. This was in 1855 and the Devonian of Iowa was then virgin territory. Here he must have met Hall who spent a few weeks at Iowa City in the autumn of 1855. At any rate during his four-year charge of the parish we find him sending choice specimens to Hall and others and gradually acquiring a knowledge of the local geology. From Iowa City he was called to Burlington where many of his spare hours for seven years were spent in making a collection of his favorite fossils, the crinoids. It was here that he met Wachsmuth and from him the latter acquired his first knowledge of geology and paleontology, a knowledge which bore such abundant fruit in later years. From Burlington, Barris was called to Davenport where he spent the remainder of a busy and useful life. Here he kept up his paleontological interests and continued writing papers on geology and paleontology, a work which he had already begun at Burlington. At Davenport he studied especially the Devonian blastoids and his contribution to the knowledge of this class ranks among the best done in America. His frequent excursions to northern Michigan resulted in the discovery about Alpena and elsewhere of many specimens of blastoids identical with those found at Davenport and serving as indexes for the correlation of the Devonian of the two areas. Nor were the crinoids of the region about Davenport neglected in his devotion to the blastoids. The fact that he found a large number of almost perfect specimens in an area where crinoidal remains are especially fragmentary is a testimony to his untiring energy. His new genus *Stereocrinus* and the species of the following list are from the Iowa Devonian:

Nucleocrinus obovatus
Nucleocrinus meloniformis
Stereocrinus triangulatus
Stereocrinus triangulatus var. liratus
Megistocrinus nodosus.

Two of the species described in this report have been named in his honor and he collected the types of others. Frequent allusions to his contributions occur under the description of species, in the following pages.

Dr. Chas. A. White, state Geologist of Iowa from 1866 to 1870, was a paleontologist of much ability. Being a resident of Burlington for many years, where he knew Barris and Wachsmuth intimately, his chief paleontological work in Iowa naturally was done with Mississippian, especially with Kinderhook, fossils. However, in a paper by him in the Proceedings of the Philadelphia Academy we find the description of a new Devonian genus of cystids, *Strobilocystites,* and of the species *S. calvini* named for its finder Doctor Calvin who found the types near Iowa City. In the same paper White described the crinoid *Megistocrinus farnsworthi,* a rare species also from the vicinity of Iowa City.

It is not surprising that Prof. A. H. Worthen, who assisted Hall with his Geology of Iowa, should have been familiar with the Iowa Devonian. Worthen was later State Geologist of Illinois. Inasmuch as the Devonian of Iowa extends across the river in the vicinity of Rock Island, Worthen, in the pursuit of his studies of the Illinois Devonian, collected fossils on both sides of the river. Two species of crinoids described by him in the Illinois reports are from the Iowa side, one, *Deltacrinus barrisi* from Davenport, and the other, *Poteriocrinus buffaloënsis,* from a ravine near Buffalo. Some years earlier he and Prof. F. B. Meek had described *Eutaxocrinus gracilis* in the Proceedings of the Philadelphia Academy. The type specimen of this species also came from Buffalo.

The names of Wachsmuth and Springer will forever be associated with American echinodermology. Their great monograph on the Crinoidea Camerata includes all North American crinoids of that order known up to the time of its publication in 1897. The noted Burlington beds furnished the greater part of their extensive and beautiful collection of crinoids. Wachsmuth lived at Burlington where Springer came to practice law upon his graduation. The happy association of these two men, their profound knowledge of these interesting fossils, and their friendly attitude and helpful suggestions, drew paleontologists and collectors to them in fullest confidence. Wachsmuth was ever ready to aid others where he could, Springer generously passed an opinion on any specimen sent or brought him for identification. In the collections at the University of Iowa are many fine blastoids and crinoids obtained by Calvin from one or the other of these two men, while a magnificent collection of the Burlington crinoids was presented to the University by Doctor Springer several years ago. On the other hand Professor Calvin delighted in referring such crinoids as he found to them for determination and study. The writer recalls a fine flexible crinoid collected by Calvin in the Hamilton shale at Thedford, Ontario; in due time he apprised Springer of his find and years later the specimen appeared as a cotype of one of Springer's new species. From the Iowa Devonian three new camerates were described in Wachsmuth and Springer's famous monograph. These are *Melocrinus tiffanyi, Melocrinus calvini,* and *Hexacrinus occidentalis.* They were collected respectively by A. S. Tiffany at Buffalo, by Samuel Calvin at Solon, and by W. H. Barris at Davenport.

In Dr. Frank Springer's recent monograph on the Crinoidea Flexibilia appears a description and illustration of a remarkably fine new species, *Euryocrinus barrisi,* from Buffalo. Three other flexible crinoids from our Devonian have been admirably illustrated and redescribed in this scholarly treatise.

Dr. Samuel Calvin, head of the department of geology at the University of Iowa for close to forty years and state geologist for nearly twenty years, was a close and critical student of the Iowa Devonian. He prepared the greater number of the reports of the counties where the Devonian belt outcrops and made extensive collections of the fossils, among them being six of the new species of this paper. Most of these were accumulated subsequent to the appearance of the Monograph on the Camerata. In spite of a busy life in the class room, in the field, and in the pursuit of various duties related to the administrative functions of his offices as state geologist and department head, he found time to describe a large number of fossils. This Calvin did so well that it is regrettable that he did not have ample time to devote to the study of his collections. Only one echinoderm, a cystid, *Strobilocystites polleyi,* was diagnosed by him. This was collected by one of his students in the Devonian of Cedar county. The chief contribution of Calvin, however, was not in the new species he described, nor in the geological papers and reports which he wrote, excellent as they were, but in the inspiration and enthusiasm he imparted to his students.

Many others have contributed in a more or less direct way to the literature of the subject. Prof. R. P. Whitfield, for example, published the first illustration of *Melocrinus nodosus.* Mr. A. S. Tiffany in a paper on the "Geology of Scott County, Iowa, and Rock Island County, Illinois," published in 1885, listed a great many species from the Devonian, among them ten genera, some with "undetermined or new species," and nine species of blastoids and crinoids. Most of these, however, appear to have been incorrectly identified, at least most of them do not occur on the Iowa side and in Mr. W. E. Ekblaw's paper on the "Correlation of the Devonian System of the Rock Island Region," published in 1912, no echinoderms are listed. Various papers by Mr. C. L. Webster refer to the occurrence of crinoids in the Devonian rocks of the state; allusion to his reporting a *Strobilocystites* from Floyd county is made under one of the species of that genus. Mr. C. L. Fenton's list of "Hackberry" fossils includes one genus of crinoids and one of echinoids.

In 1919 the writer read a preliminary paper before the Paleontological Society of America on "Echinoderms of the Iowa Devonian." It appeared in abstract form in the Proceedings of the Geological Society of America for 1920, pages 211, 212. In this are presented briefly some facts concerning the echinoderms already described; the genera *Arthracantha, Dactylocrinus, Decadocrinus, Cyathocrinus,* and *Xenocidaris* are reported for the first time; and a brief diagnosis is given of two new genera of echinoids, namely *Devonocidaris* and *Nortonechinus.* The *Dolatocrinus* mentioned in the abstract has proved to be a *Stereocrinus* and the doubtful *Lecanocrinus* turns out to be a new species of *Clidochirus.* In the same year the writer read two short papers bearing on the Iowa Devonian before the Iowa Academy of Science; one on "The Fauna of the Independence Shale," pointing out among other things the occurrence of *Arthracantha* in Iowa, and the other on "*Nortonechinus,* a Devonian sea urchin." Abstracts of these appeared in Science, July 23, 1920, p. 89. At the meeting of the Iowa Academy of Science in April, 1923, another paper was read entitled "The Geographic Distribution of Iowa Devonian Echinoderms." The chief points in the paper had already been prepared for, and they appear in, this report.

What Echinoderms are and which are represented in the Iowa Devonian

Echinoderms are invertebrate animals that have always lived in the sea. Common examples known to most people are the crinoids or sea-lilies, the starfishes, and the sea-urchins. Scientists make three groups of them and these are again considerably subdivided. They are: I. PELMATOZOA, which with a few exceptions are fixed by a jointed and flexible stem during their post-larval life—here belong the cystoids, blastoids, and crinoids. II. ASTEROZOA, which have star-shaped bodies and are stemless and hence have freedom of movement over the sea floor. The well known starfishes and brittle stars are assigned to this group. III. ECHINOZOA, which are free and without arms, their bodies being globular or heart-shaped as in the sea-urchins, disc-shaped as in the sand dollar, or enclosed in an elongate leathery integument, an example of which is the sea-cucumber.

Echinoderms have had a very long geological history as is shown by the fact that their fossil remains are found in some of the oldest rocks known to contain organic remains. Their progress from early times down to the recent is a fascinating story—now one class and later another is in the ascendancy—here the rocks are filled, literally crowded, with their skeletons, there not a trace of any of them is found. Of the seven classes two of them, the cystoids and blastoids, are extinct. They were limited to the Paleozoic. The cystoids thrived in the Ordovician and Silurian and had become very rare in the Devonian, a fact which adds interest to the species of Iowa *Strobilocystites* which are found in the highest beds in which rhomb-bearing Cystoidea are known to occur. The blastoids, however, continued on beyond the Devonian and culminated in the next period. Of the four orders of crinoids, two of them, the Camerata and Flexibilia, disappeared before the end of the Paleozoic, the third order, the Inadunata, continued on into the Mesozoic, while the last, the Articulata, began about the close of the Paleozoic and contains all the living crinoids. Fossil representatives of the first three orders occur in the rocks embraced in this study. The Asteroidea, or starfishes, which are abundant to-day, may be traced back to Cambrian times. No remains of these or of the next have been found in the Iowa Devonian. The brittle stars, or Ophiuroidea, are common in the modern seas but their fossil record, though dating back to early Paleozoic, is meager. The Echinoidea, or sea-urchins, have been a part of the world's marine fauna from the Ordovician to the Recent. They have been especially abundant during the Mesozoic and Cenozoic. Their Paleozoic evolution is a fascinating story and it is a pleasure to add not a little to that account in this paper. One order, the Perischoëchinoida, is represented in the Iowa Devonian by three genera and five species. The Holothuroidea, or sea-cucumbers, because of their poorly developed skeletal parts, have left but a very scant paleontological record. However, Walcott has undoubted specimens from the Cambrian of British Columbia and there are straggling bits of evidence down through the geologic eras connecting those early representatives with the modern forms.

The classes, orders, and families of echinoderms found in the Devonian of our area may be arranged in tabular form as follows:

Classes	Orders	Families
Cystoidea	Rhombifera	Callocystidae
	Edrioasteroidea	Agelacrinidae
Blastoidea	Eublastoidea	Codasteridae
		Nucleocrinidae
Crinoidea	Camerata	Melocrinidae
		Batocrinidae
		Hexacrinidae
	Flexibilia	Ichthyocrinidae
		Taxocrinidae
	Inadunata	Synbathocrinidae
		Cremacrinidae
		Cyathocrinidae
		Poteriocrinidae
Echinoidea	Perischoëchinoida	Archeocidaridae
		Lepidocentridae

Preservation and Abundance of the Echinoderm Remains

The echinoderm remains in the Iowa Devonian are scanty when compared with the prodigal abundance of the same class of remains in the overlying Mississippian strata as exemplified in the classical localities at Burlington, Keokuk, Le Grand and elsewhere in the state. Yet certain zones in the Devonian are so filled with crinoidal remains that they form "encrinal" or crinoidal limestone. In fact stem ossicles of crinoids are common fossils at nearly every locality where fossils of any kind occur. Good calyces, however, are rare and are not confined to any particular locality, although, in general, the ravines in the vicinity of Buffalo, Scott county, the *Megistocrinus* beds near Solon, Johnson county, and certain layers to be pointed out more fully later near Brandon have produced many fine specimens. To these may be added certain layers of argillaceous limestone near Iowa City, a patch of weathered limestone in the suburbs of Waterloo, and a few exposures of the Lime Creek beds in Floyd and Cerro Gordo counties. Other less important horizons will be mentioned under the discussion of the different species.

With few exceptions the specimens studied are preserved as calcite in the limestones or shales. The readiness with which this mineral splits along its cleavage planes makes both the removal and the cleaning of specimens difficult and tedious. The task, for example, of cleaning the specimen described as *Melocrinus nodosus irregularis* required many hours of very close work since when it was found only five or six of its nodose plates were free from the tough hard matrix. As a rule, however, careful work is rewarded by the uncovering of traceable sutures, which are quite necessary for the correct identification and elucidation of the specimen. In the case of specimens where the sutures are too faint for photographing they have been traced in ink.

The specimens of *Megistocrinus clarkei* from Waterloo are silicified as is also the type of *Melocrinus linderi* from near Iowa City. Except for the type specimens of *M. clarkei* and *Hexacrinus occidentalis* none of the camerate crinoids studied preserves the arms. The preservation of the arms and in some cases bits of the stem is the rule, however, among the flexible and inadunate species.

In all cases where possible, strata containing abundant crinoidal or similar fragments have been traced laterally and in a few cases small areas have been located where the stratum is weathered into a marly shale. These places are a collector's bonanza. If quantities of such material are sifted through a set of fine-meshed sieves placed one above the other—the coarsest above—a large quantity not only of echinodermal fragments but of other small fossils as well may be found. A zone near Brandon yields an abundance of the nodose plates of *Megistocrinus pernodosus,* another below Nora Springs yields plates of *Hexacrinus springeri,* while surprisingly good results have been obtained in the different zones of the Lime Creek shales.[1] Here parts of echinoids have been found; teeth, braces, and

1 Bull. Geol. Soc. Amer., vol. 32, pp. 130,131; 1921.

other parts of the lantern as well as delicate ambulacral plates and spines were thus recovered. At several localities in the Lime Creek a quantity of the plates of *Clidochirus iowensis* may be obtained; from such a lot the author has selected a set which if united would make a fairly good reconstruction of the calyx to the bases of the arms, see plate XLIII; it should be added that several sets of the attached infrabasals have been obtained which aided materially in a proper understanding of the species. From the Independence shale but three or four radial plates of an undoubted *Arthacantha* were collected. On the basis of these a new species is described. Now the question can properly be asked as to what extent may species or genera be founded on dissociated parts of crinoids or echinoids. The author is well aware that it is possible to go too far in establishing species on insufficient material, perhaps he has done so, but here are the fossils and some names are needed in order to use them. It is conceded that the radials of an *Arthacantha* or of a *Cyathocrinus* or the spines and plates of an echinoid are much less desirable than complete specimens. But complete specimens have been sought more or less in vain. The next visit may yield one and then it will be seen to what extent we have erred. At any rate years have elapsed in the preparation of this paper partly at least because the hope has been entertained that more or less complete specimens eventually would be obtained. This actually happened in the case of one of the echinoids when Mr. C. H. Belanski found a part of an interambulacrum of *Nortonechinus welleri.* It was a thrilling discovery and the finder deserves great praise for his persistence. However, a study of the loose plates and spines mounted on a ball of modeller's clay had determined beforehand the mode of imbrication of the plates, the position and relation of the spines, and other facts. The accuracy of the restoration was almost wholly corroborated by the arrangement of the plates and by the position of a few spines held by the matrix to the piece of interambulacrum. This is not an argument that dissociated material can be restored in all cases, indeed, in many instances it is hazardous to attempt it at all. The writer, however, does want to make the point that where material is distinctly different from any with which it is associated and when it possesses unmistakable characters such as the arm facet on the radial of a *Cyathocrinus* or the spine sockets on the radial of an *Arthracantha* generic recognition is certain. And, too, when these dissociated parts are limited to a more or less distinct zone and are geographically remote, as is the case with *Arthracantha,* from other species of the genus then specific rank can be assigned with reasonable safety from duplication.

A few illustrations of unidentified forms such as stem segments, parts of calyces, and so on, have been entered on one or two plates. The number might have been extended but enough have been introduced to show that there are other species awaiting the student when better material is obtained.

The Distribution of some of the Genera and Species.

Of the forty-three species and two varieties described in this paper only seven of the species are reported as occurring outside the state. These are:

Nucleocrinus obovatus	Iowa, Wisconsin, Michigan.
N. meloniformis	Iowa, Michigan.
Melocrinus nodosus	Iowa, Wisconsin.
Megistocrinus nodosus	Iowa, Michigan.
Euryocrinus barrisi	Iowa, Michigan.
Synbathocrinus matutinus	Iowa, Michigan.
Deltacrinus barrisi	Iowa, Illinois.

It is to be noted that these species do not range far beyond the confines of the state and are practically limited to the Dakotan sea and Traverse basin of Schuchert.[2] It may be expected that when the faunas of these basins are better known the above species will be found to extend more widely and that the range of other species here described will spread beyond their present known limits. Indeed, closely allied if not the same species do occur in the Missouri Devonian (Callaway county) and when the Devonian of Canada, extending from Manitoba to the Mackenzie valley, is better known some of our species may be expected in this northern region, if the sea connections were in this direction. Very few of the

2 Bull. Geol. Soc. Amer., vol. 20, p. 545; 1910.

Iowa species have extensive vertical distribution, being limited in most cases to rather narrow zones. In this connection it may be pointed out that of the seven echinoderm genera occurring in the Lime Creek beds only three are found in the underlying Devonian beds. Moreover the geographical extent of most species, as now known, is somewhat restricted.

Of the twenty-two genera only three are wholly limited to the Iowa Devonian; these are *Strobilocystites, Nortonechinus,* and *Devonocidaris.* Nine occur in the Devonian of the neighboring states of Illinois, Wisconsin, Missouri, and Michigan; twelve are found in the New York Devonian;[3] *Stereocrinus* occurs also in Tennessee; six are found in the Kentucky-West Virginia-Ohio region; three are reported from Canada; and eight from Europe. The vertical extent of these genera is interesting in that six of them begin in the Silurian, of which six four lived on to the basal Mississippian; the others arise in the Devonian and seven of these also continue to the Mississippian; eight genera are limited to the Devonian. It may be noted that only six of our genera begin below the Devonian but that eleven or half of them continue to the Mississippian; this fact tends to emphazise a late Devonian age for the Iowa rocks containing the fauna here discussed. In compiling these figues on vertical range *Agelacrinites* has not been considered since the writer is of the opinion that many pre-Devonian species assigned to this genus are generically distinct from those of the Devonian.

The following table, though incomplete, brings out in another way the facts just presented.

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3 Fourteenth Rept. Dir. N. Y. State Mus., pp. 47, 48; 1918.

	Iowa	Missouri	Illinois	Wisconsin	Michigan	New York	Tennessee	Kentucky	Ohio	West Virginia	Canada	France	England	Belgium	Russia	Germany	Silurian	Devonian			Mississippian
																		Lower	Middle	Upper	
Strobilocystites	X																			–	
Agelacrinites	X					X											...	—	—	—	
Nucleocrinus	X			X	X	X		X											—	—	
Codaster	X				X			X									—	—	—	—	—
Melocrinus	X	X		X		X			X		X	X		X		X	—	—	—	—	
Stereocrinus	X						X											—	—	–	
Megistocrinus	X				X	X		X	X										—	—	–
Hexacrinus	X							X					X	X		X		.	—	—	
Arthracantha	X					X					X									—	
Clidochirus	X					X				X							—	—	—	—	–
Euryocrinus	X				X															—	–
Dactylocrinus	X	X			X									X	X	X			—	—	—
Eutaxocrinus	X					X					X			X		X	—	—	—	—	—
Taxocrinus	X			X		X							X						—	—	—
Synbathocrinus	X				X	X													–	—	—
Deltacrinus	X		X			X										X	—	—	—	—	
Cyathocrinus	X															X	—	—	—	—	–
Poteriocrinus	X					X													—	—	–
Decadocrinus	X					X													—	—	–
Nortonechinus	X																			–	
Xenocidaris	X															X			–	—	
Devonocidaris	X																			–	

Fig. 60. Table showing geographic and stratigraphic distribution of the echinoderm genera occurring in the Iowa Devonian.

The distribution of some of the Devonian genera in Iowa, in the surrounding states, in Canada, and on east into Kentucky and New York has been so well stated in a recent publication by Dr. Frank Springer that the statement is here quoted in full:

> "At Louisville *Dolatocrinus* is the leading genus, followed by *Megistocrinus, Nucleocrinus, Codaster,* etc., but no sign of *Melocrinus* or of any Flexible crinoid; in Callaway County, Missouri, *Melocrinus* occurs, and an Ichthyocrinoid of the genus *Dactylocrinus,* but no *Dolatocrinus* or *Megistocrinus;* in Iowa *Megistocrinus* and *Melocrinus* and a notable new Ichthyocrinoid, but no *Dolatocrinus;* in northern Michigan, *Dolatocrinus, Megistocrinus, Nucleocrinus,* and *Codaster,* of species mostly well differentiated from those of the Louisville area; in Wisconsin, *Melocrinus* closely similar to the Missouri species, forms which also extend far to the north in the McKenzie Basin, Canada; in the last four areas, not including the Canadian, species belonging to the Flexibilia occur, of different forms in each. In western New York and Ontario, *Dolatocrinus* and *Megistocrinus* closely related to the Louisville forms occur; but in addition to these an extraordinary assemblage of the other forms not represented in either of the other areas, which are soon to be described in a Memoir by the New York State Museum."[4]

It is noteworthy that while the Devonian terrane of Iowa extends for some distance into Rock Island county, Illinois, and also northward into the southern tier of counties in Minnesota very meager echinodermal remains have ever been reported from either area. Ekblaw's long list of fossils from the Devonian of the Rock Island region includes none[5] while Doctor Stauffer's lists from the Devonian of Minnesota includes only "crinoid stems."[6] These facts emphasize the rarity of identifiable specimens.

The finding in Iowa of *Arthracantha,* heretofore limited to the vicinity of Lake Erie, of *Dactylocrinus,* a rare but worldwide genus, of the meagerly known Rhenish *Xenocidaris,* and

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4 Bull. 115, U. S. Nat. Mus., p. 20, ftn.; 1921.
5 Trans. Ill. Acad. Sci., 1912 (Unpaged reprint).
6 Amer. Jour. Sci., vol. IV, pp. 403, 406; Nov., 1922.

of the genus *Agelacrinites,* are important contributions to the distribution of these genera. Perhaps the most interesting fact in the study of distribution is the presence of certain European genera, especially those of the Rhenish Devonian. In the opinion of the writer further study, especially of the echinoids, will still further emphasize the relationship of our Devonian with that of the Eifel.

Some Significant Facts Brought Out by the Study

Aside from the fact that the study has resulted in a number of new species and in new locality and horizon records for others there are a number of interesting points deserving of brief mention.

The abundance of encrinal limestone and the rarity of complete or identifiable specimens are accentuated by the fact that close to half the species described and illustrated are known only from single specimens or from one specimen and fragments of others. That these are good species there is little doubt in any case but they do illustrate the fact that exceedingly few individuals have escaped falling apart.

The assemblage here elucidated is remarkable for the number of species which have nodose plates or some form of spines or excrescences. Of the six Melocrinids only one has smooth plates, three of the Megistocrinids are nodose, one of them remarkably so, and *Arthracantha* and *Stereocrinus* have their special forms of decoration. The echinoid genera are unique in the matter of spines. *Nortonechinus* and *Xenocidaris* have spines of so abnormal a nature as to suggest their being cidaroid rather than perischoëchinoid genera. In fact the latter genus has been doubtfully included with the cidarids in the second edition of Zittel's Textbook of Paleontology.

The rhomb-bearing cystids of the Iowa Devonian are the latest known species of this order, the group having reached its climax in the Ordovician or Silurian, with a good showing in the Lower Devonian. It is rather surprising that *Strobilocystites* has not been recognized in other parts of our basin as have our equally rare and interesting species of the blastoid, *Nucleocrinus*.

The genera *Melocrinus* and *Megistocrinus* are represented by six and eight species respectively. The latter is by far the most common genus in the area and most of the crinoidal limestone is largely made up of dissociated calyces, arms, and stems of its species.

Hexacrinus, though a common genus in Europe, is rare in America. Up to the writing of this report only two species were known from America and these by but a few specimens. One of the two, *H. occidentalis,* already described from Iowa, is here accompanied by two others bringing the American total to four—three of them from Iowa. The most gratifying fact, however, is that a definite zone bearing *Hexacrinus* plates has been found and traced for several miles. Scores of the plates have been collected and complete calyces may confidently be expected upon closer search.

And finally the most remarkable part of the study is the notable echinoid material found in the Lime Creek beds. Paleozoic echinoderms are rare, especially below the Mississippian. The Ordovician and Silurian have contributed a few while eleven species have previously been obtained from the Devonian. Seven of these, belonging to three different genera, are from the Rhineland, two are from England and two from New York. A tabular arrangement follows:

Eocidaris laevispina (Sandberger)	Germany
Lepidocentrus rhenanus (Beyrich)	Germany
L. mülleri Schultze	Germany
L. eifelianus Müller	Germany
Xenocidaris clavigera Schultze	Germany
X. conifera Schlüter	Germany
X. cylindrica Schultze	Germany
Lepidesthes devonicans Whidborne	England
Pholidocidaris acuaria (Whidborne)	England
Lepidocentrus drydenensis (Vanuxem)	New York
Lepidechinoides ithacensis Olsson	New York

It is regrettable that our echinoid material is dissociated, but the individual plates, spines, and other parts are very well preserved and the material is in places very abundant. The reader may judge for himself as to the interpretation put upon the specimens by the writer, and whether right or wrong an honest attempt has been made to describe the material as it occurs.

No echinoid remains have been seen in the Cedar Valley beds though close search has been made in certain zones; enough, but very imperfect, material has been found in the Shell Rock limestone, however, to assure us that a few scattered echinoids lived at the time of its deposition. Since writing the greater part of this paper certain plates and spines have been found in the Owen beds, which are the uppermost strata of the Iowa Devonian and at some distance above the zones containing *Nortonechinus* and *Devonocidaris*. In many respects the plates resemble those of *Lepidocentrus* rather than those of *Nortonechinus*. Unfortunately they are so worn as to obscure some of the details necessary for correct generic diagnosis.

The Iowa Devonian

The Iowa Devonian is composed of a body of limestone, dolomitic in places, and shales. These outcrop in a diagonal belt forty to sixty miles wide extending across the state from the middle of the northern boundary to Davenport on the eastern border. They continue for some distance northward into Minnesota where they disappear beneath younger strata, and also southeastward into Rock Island county, Illinois, where again they disappear below younger rocks. The various members of the system dip gently to the southwest; they have been but little disturbed by folding or faulting except in a minor way locally and that has been largely in connection with brecciation which has crushed and distorted the lower terranes over a part of the area.

A complete discussion of the Devonian system, as developed in Iowa, will appear in another paper, now in preparation. The synoptic table given below will serve as a convenient reference in connection with the geological position of the species described in this paper.

Devonian	Upper Devonian	Lime Creek-State Quarry	
		(Break)	
		Cedar Valley	
		Wapsipinicon	Davenport { Upper / Lower } Independence Otis

Fig 61. Table showing divisions of Iowa Devonian.

As shown in the table all the Iowa Devonian is here assigned for the first time to the Upper Devonian. White[7] was of the opinion that it all belongs to one series and influenced by Hall and others, he correlated it with the Hamilton of the Middle Devonian. Later Hall and Whitfield assigned the Lime Creek beds to the Chemung[8] but left the subjacent beds in the Middle Devonian. To the Upper Devonian assignment, Calvin later added the State Quarry beds which also are separated from the Cedar Valley by an erosion interval. The Sweetland Creek beds of Muscatine county are likewise set off by an erosional unconformity from the Cedar Valley. Calvin placed them in the Upper Devonian but there is some doubt about their stratigraphic position since the fossil evidence is indecisive and Kinderhook may well be their final assignment.[9]

Weller[10] in his paper on the "Correlation of the Middle and Upper Devonian and the Mississippian Faunas of North America" placed the Cedar Valley as contemporaneous with the Portage and the Wapsipinicon as the time equivalent of the later Hamilton. The tendency has been to follow this correlation in the main, leaving only a part of the Wapsipinicon in the Middle Devonian. Schuchert in his table has practically followed the above and the Iowa Survey has tentatively ac-

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7 Geol. Surv. Iowa, vol. I, p. 187; 1870.

8 Twenty-third Ann. Rept. N. Y. St. Mus., 225, 226; 1873.

9 Weller, Jour. Geol, XVII, pp. 266, 267; 1909. Textbook of Geology, A. W. Grabau, Part II, p. 443, Heath & Co., N. Y., 1921.

10 loc. cit., p. 266.

cepted the usage.[11] The line of separation has been regarded as the horizon of *Hypothyridina cuboides* in the upper part of the Wapsipinicon. Beds below this horizon, such as the Independence shales and the Otis, have been placed in the upper part of the Middle Devonian series. Since the fauna of the Independence shale has certain affinities with that of the Lime Creek and since the chief fossil of the Otis is a species akin to *Martinia subumbona* it impresses the writer that it is more logical to place all the Devonian in one series especially as there is no noticeable stratigraphic break either within or at the close of the Wapsipinicon. The Wapsipinicon-Cedar Valley line is based almost wholly on paleontological grounds, being formerly drawn by Norton just above the *Phillipsastrea* horizon and by Calvin just below this coral bed.[12] The *Spirifer pennatus* beds, too, have been held to be the highest part of the Upper Davenport. At some exposures where the above species are absent a detailed study of the fauna is necessary. As a rule the fine-ribbed *Atrypa reticularis* (*Atrypa independencis* Webster, 1921), *Gypidula comis* (Owen) and some others do not pass up into the basal Cedar Valley. At several outcrops the separation is largely a matter of paleontology although lithology and brecciation aid appreciably in many localities. Recently the situation has been well summarized by Norton.[13]

The Cedar Valley is very variable both lithologically and faunally as it is traced from point to point. Substage names that apply fairly well have been proposed for the strata of Johnson county[14] but these can not be applied along Mississippi river nor in the northern half of the terrane. A glance at a geological map of Iowa will show that the Devonian belt is considerably wider in the northern tiers of counties than in the central or southeastern parts of the state. This is true regardless of the distribution of the Lime Creek stage. Since the general amount of dip is not appreciably different in northern Iowa and since the Wapsipinicon outcrop narrows north-

11 Paleogeography of North America. Bull. G. S. A., vol. 20, p. 541; 1910.
12 Iowa Geol. Surv., vol. ix, p. 452; 1899.
13 Iowa Geol. Surv., vol. xxvii, pp. 362-370; 1921.
14 Iowa Acad. of Sci., vol. xix, pp. 149, 150; 1912.

ward and disappears in Howard county, the combined thickness of the Cedar Valley substages is greater in the northern counties than in the latitude, for example, of Iowa City. The wider distribution in the northern counties is partly explained by the eastward extension of the Cedar Valley until it overlaps the Ordovician.[15] However, in parts of Butler, Floyd, northeastern Cerro Gordo, and counties to the north there come in recognizable formations which are higher and faunally separ-

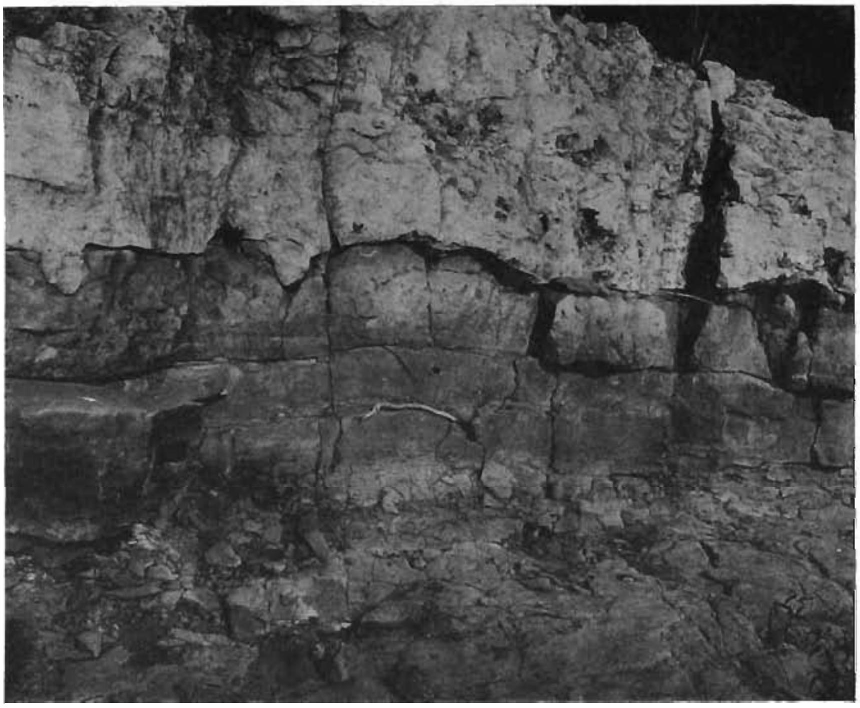

FIG. 62—Contact between the Nora limestone and the Mason City dolomite, left bank of Lime creek, near the north line of section 16, township 95 north, range 18 west. The part of the Nora shown in the figure is the white limestone of the lower *Actinostroma* horizon. The total thickness of the Nora at this point is twenty-two feet; over it lies six or seven feet of the basal blue shale of the Lime Creek stage. (*Photo by Calvin.*)

able from the Cedar Valley. They are not thick, probably not exceeding one hundred feet in vertical extent. The general group of these is called the Shell Rock limestone from their typical development along Shell Rock river between Rockford and Nora Springs and on northward, also about Mason City and

15 Iowa Geol. Surv., vol. xiii, p. 38; 1903.

to the north and northwest. The upper member of this group is the Nora limestone,[16] whose sharp contact with the basal blue shale of the Lime Creek stage may be seen on Lime Creek just west of the town of Rockford. Below the Nora at this point and separated by a slight erosional unconformity is a dolomitic limestone, the Mason City dolomite of Calvin.[17] This formation is well developed in and about Mason City, at Nora Springs, and on south of the latter place along the river. It is suggested that eventually the Shell Rock may be made a stage with the Nora, Mason City, and possibly other horizons as substages. Space does not permit further elaboration here and moreover detailed stratigraphic discussions are outside the scope of this paper.

Acknowledgments

In the preparation of a report of this nature extending over a period of years many persons are solicited in one way or another for suggestions, for specimens, for literature, and for other matters incidental to the problem. It is a pleasure to acknowledge here that without exception everyone has been most ready to comply.

One of the features of this report, as of any similar report, consists of the new species, especially those of more than local interest. So many of the fine and rare species here described have been collected by Mr. C. H. Belanski that it is difficult properly to express the debt this contribution owes him. He is an intelligent and indefatigable collector and a keen observer. He has generously turned over hundreds of fine specimens from northern Iowa to the writer for study. Many of these, including types, have been donated to the paleontological collections at the University. The types of the following species were collected by him: *Melocrinus belanskii, Hexacrinus springeri, Hexacrinus iowensis, Dactylocrinus stellatimbasalis, Nortonechinus welleri, Strobilocystites schucherti,* and he has contributed the cotypes of as many more.

An excellent collection of Johnson county echinoderms was

[16] Science, n. s., vol. 37, p. 459; 1913.
[17] Geol. Surv. Iowa, vol. VII, p. 144, in table; 1897.

kindly submitted for study by Mr. T. J. Fitzpatrick. The collection is the property of and was collected by Mr. Fitzpatrick and his wife, Mary Frances Linder Fitzpatrick. They were accompanied by the collector's full field notes. One of the specimens in this lot is credited to Mr. Fitzpatrick's father-in-law, Mr. Anton Linder.[18]

The residue of the Barris collection, consisting of several fine blastoids and crinoids, some of them type species, was loaned for study by the Davenport Academy of Science through the kindness of the curator, Prof. J. H. Paarmann.

Mrs. David Brant deserves especial mention for contributing to the study an instructive lot of beautiful specimens of *Megistocrinus clarkei* collected at Waterloo.

To Doctor W. H. Norton the writer is especially indebted for the first lot of echinoid spines and plates from the Lime Creek beds and for other specimens as well as for many valuable notes and suggestions drawn from his rich field experience in the Iowa Devonian.

For still other specimens the writer has to thank his students who have at all times enthusiastically contributed from their collections. Individual mention is made under the appropriate species.

Especial thanks are due several individuals who have helped in other ways. To Doctor Frank Springer much is due. He kindly aided in the identification of several species, he contributed literature and prints, and his words of encouragement have been greatly appreciated. Doctor Robert Tracy Jackson has been helpful, and his opinions on some of the echinoid remains aided materially. Doctor F. A. Bather, of the British Museum, has kindly furnished indispensable literature. Professor Stuart Weller has offered much valuable counsel and has carefully examined some of the specimens.

Doctor Otto T. Walter has made many of the drawings and has aided in cleaning and cataloging the material. Mr. Merrill A. Stainbrook has been of much help in the photographic work.

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18 Since the above was written Mr. Linder has passed away in his one hundred and first year.

He has also collected several fine specimens, some of them new species.

To his colleagues in the department and to the officers of the State Geological Survey the author is especially grateful for many valuable suggestions and for their hearty coöperation.

Description of the Genera and Species.

CYSTOIDEA von Buch
RHOMBIFERA Zittel
CALLOCYSTIDAE Bernard

STROBILOCYSTITES White
= STROBILOCYSTIS Bather

Calyx ovoid or subspherical, with eighteen plates in four cycles. Ambulacra four, which may or may not give off secondary branches. Pectinirhombs three, their halves separated, and situated on plates 1 and 5, 14 and 15, and 12 and 18, one rhomb on each of the four parts of the calyx as defined by the ambulacra except on the posterior part; rhombs of the right and left parts are above the middle of the calyx, that of the anterior part near the base; the long diagonal of the left rhomb is nearly at right angles to the vertical axis of the calyx, that of the right nearly parallel to it, and that of the anterior rhomb obliquely transverse. Anal pyramid situated adorally on the posterior and narrowest quadrant and composed of six pieces and an outer circle of nine pieces. A double madreporite and minute hydropore on plate 23. Column stout, tapering.

Genus callocystine in character and fairly close to Hall's *Sphaerocystites* there being some telescoping of the second and third cycles, but plate 12 is not in contact with plate 2 as is the case in some species at least of that genus. *Strobilocystites* is limited to the Iowa Devonian so far as is now known.

STROBILOCYSTITES CALVINI White
Plate XXXV, figs. 1-11, 13, 18.

1876. *Strobilocystites calvini* White. Proc. Acad. Nat. Sci. Philadelphia, vol. 28, p. 28.

1883. *Strobilocystites calvini* Calvin. History of Johnson County, Iowa, Notes on the fossils, pp. 558, 560.

Body globular to ovoid or depressed. Ambulacra four, branching irregularly, the number of branches being from two to seven on each ambulacrum—those on either side of the anal pore tending to have the fewest number; ambulacra and branches are set into broad depressions in the theca and they cover most of the surface between and around the anus and pectinirhombs thus obscuring the suture lines between the thecal plates; the main trunk of each ambulacrum reaches quite to the base; ambulacral plates alternating, slightly elevated, each bearing a brachiole facet which facets are from one to three millimeters apart, ambulacral groove zigzag, narrow, and deep; covering plates or ambulacralia and brachioles are lost.

Pectinirhombs three, their two parts wholly separated by a suture line, each half deep set and limited by a sharp bounding ridge and containing from twenty-four to thirty-two dichopores; on some weathered specimens the connecting ducts which extend within the plates from the dichopores to the line of suture are exposed.

Anal pyramid low, made up of a rosette of six small pieces encircled by two or three large aboral and six or seven smaller plates. Madreporite situated on plate 23, and composed of two oval, subequal areas with concave surfaces and each surrounded by a sharply raised rim; hydropore small, situated betweeen distal ends of the madreporite areas, its pyramid not observed.

Surfaces of thecal plates where not obscured by the ambulacra are marked by a maze of low papillose nodes and discontinuous ridges.

Stem opening large, round or rounded-oval, the part in the plates countersunk and "having no articulating striae." (Troost, Bull. 64, U. S. N. M., p. 9.) Stem round, tapering, and slightly curved; the lumen large; segments appear to be telescoped one within the other, their peripheries angular.

The better of the two specimens available to White is the type on which he based his generic and specific descriptions. It was collected by Doctor Calvin near Iowa City[19]. The other specimen is considerably damaged by exfoliation and the base is broken off. It is a little larger than the type. Since that time fifteen or twenty additional specimens have been collected in the state. The majority of these, too, average considerably larger than White's type.

Position and localities.—The Iowa City specimens, so far as is known, have been found at the Sanders quarry, on the left bank of Iowa river on the "Dubuque road" near the north limits of the city at a level about fifteen to twenty feet above the ordinary stage of the river. They occur in a tough gray crystalline limestone which weathers to a friable yellowish-brown rock; the zone is approximately ten feet below the Idiostroma ledge seen near the top of the quarry at the south end. Plates of this species associated with a specimen of *Megistocrinus latus* have been found on slabs in the sides of a small creek in northwest quarter section 8, in Penn township about a mile northeast of North Liberty; the presence of *M. latus* suggests a lower horizon than at the Sanders quarry. In 1915, Mr. J. V. Howell found a specimen and some dissociated plates on a loose slab at Aicher's quarry in section 27, township 80 north, range 6 west. One specimen at hand was collected some years ago by Mr. E. P. Whipple from Devonian outcrops about Vinton, the exact locality now unknown. One quite large but crushed specimen was collected along Lime creek, a tributary of Cedar river, in Buchanan county, by Mr. Merrill A. Stainbrook. The writer has since found two others there as well as a number of dissociated plates and a stem.

Two fine calyces in the Fitzpatrick collection are from Sanders quarry. One of them preserves eleven millimeters of a gently tapering and curved stem. The other is larger and displays a perfectly preserved anal pyramid, see drawing on Plate XXXV. A portion of the stem, freed from the calyx at the time it was collected, accompanies this specimen also.

A nearly perfect but slightly distorted calyx, also from the Sanders quarry, is in the Cornell College Museum. It was collected by one of Doctor Norton's pupils.

19 Amer. Jour. Sci., Vol. XXV, p. 434, 1883.

In some earthy dolomitic beds in the Shell Rock limestone in the vicinity of Nora Springs in Floyd county occur abundant internal molds of a *Strobilocystites* presumably of this species; a few of them show interesting molds of the pectinirhombs. Webster[20] reported this species from near Nora Springs nearly thirty years ago.

STROBILOCYSTITES POLLEYI Calvin.
Plate XXXV, figs. 14-17.

1883. *Strobilocystites polleyi* Calvin. History of Johnson County, Iowa, Notes on the fossils, pp. 558, 560.

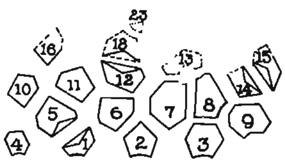

FIG. 63—Analysis of *Strobilocystites polleyi* Calvin. Plates of upper cycle in part restored.

Species based on a single specimen, the oral end of which has been broken off and from which, too, the ambulacral plates have been exfoliated. Calvin says:

> "The *S. polleyi* differs from it (*S. calvini*) in being larger, more globose, and in having the surface ornamented with minute irregular, vermicular furrows instead of the papillae that characterize the *S. calvini*. The arm-grooves of *S. polleyi* do not reach more than half way to the base."

The ambulacra, however, do reach quite to the basal circlet of plates and each is branched although the full extent of the branching is uncertain. No ambulacrum or branch invades those parts of plates 1 or 6 immediately to the right of the basal pectinirhomb as is the case in all specimens of *S. calvini* at hand. In fact the greater part of the surface of the theca is uninvaded and this together with the loss of the ambulacral plates makes it easy to trace the sutures and to make an analysis of the calyx plates.

The type was collected in the "Devonian beds of Cedar county," presumably by Mr. J. F. Polley who graduated in the engineering course at the University of Iowa in 1876 and for whom Calvin named the species. The specimen was a part of the Iowa geological exhibit at the Centennial Exposition at

20 Webster, C. L., Davenport Acad. Sci., vol. V, pp. 104, 107; 1888.

New Orleans in 1885; the display label still accompanies the specimen. The only Devonian outcrops in Cedar county likely to have yielded fossils are the exposures and quarries in sections 26, 35, and 36, township 79 north, range 3 west. These are across the county line just north of Atalissa, Muscatine county[21]. It is known that Professor Calvin and his classes frequently visited these localities in the seventies and eighties and that small quarries were in operation about this time. The horizon is the upper part of the Wapsipinicon beds with some basal Cedar Valley at the top. It is uncertain at what level the type specimen was found; at any rate the horizon of the Atalissa quarries is considerably lower than that of *S. calvini* in Johnson county to the west.

STROBILOCYSTITES SCHUCHERTI n. s.
Plate XXXV, figs. 12, 19-21.

Calyx elongate, ovoid, somewhat quadrate in cross section. Ambulacra extending to the base; in the three specimens at hand, one, number 3506, shows no branching, another, number 3505, has one prominent branch on the left anterior ambulacrum, and a third, number 3507, which is imperfect, has two short branches, one with a single ambulacral plate and another with two plates. Both branches are high up and on the same arm as in number 3505. Ambulacral plates are nodose and prominently elevated; brachiole facets seven to nine in ten millimeters on either side of the ambulacrum.

FIG. 64—Diagrams showing the arrangement and number of ambulacral branches in *Strobilocystites calvini* and the almost complete absence of branches in *Strobilocystites schucherti*.

Pectinirhombs are situated as in *S. calvini* but have fewer dichopores, there being from twelve to eighteen in each half on numbers 3505 and 3506. Moreover each half rhomb is curved or bow-shoped on these two. On number 3507 the rhombs are much as on *S. calvini*.

Madreporite small, double, the anterior area elongate and

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21 Iowa Geol. Surv., vol. XI, p. 341; 1901.

larger, the other round, both surrounded by a crater-like rim; hydropore in depressed area between the madreporites, round and but slightly smaller than the posterior madreporite.

Thecal plates smooth or nearly so in the interambulacral areas, suture lines fairly distinct. Stem opening as in previous species.

Position and localities.—Specimen 3507 from lower part of Cedar Valley beds one and one-half miles west of Solon; collected by Mr. L. P. Elliott, a former student of Professor Calvin's and an enthusiastic collector of local fossils.

Specimens 3505 and 3506 were collected by C. H. Belanski in the Shell Rock limestone in the Belanski quarry at Nora Springs, Iowa; this is approximately the zone of *Hexacrinus springeri.*

These two specimens are made the types. It is to be noted that they occur at a considerably higher horizon than number 3507 from near Solon. The latter may eventually be set off in another species when more material from this horizon is obtained. However, except for the shape of the rhombs and a few minor details, it is much like the other two.

The reduction of ambulacral branches in this species appears to be one of the indications of the extreme specialization attained by the genus before the disappearance of the rhomb bearing cystids of which it is one of the last, if not the last, representative.

The specific name is given in honor of Professor Charles Schuchert and in appreciation of his excellent papers on the Cystidea of the Lower Devonian of Maryland and West Virginia.

EDRIOASTEROIDEA Billings

AGELACRINIDAE Hall.

AGELACRINITES HANOVERI n. s.

Plate XLVI, figs. 1-5.

Body compressed, circular, sessile, and permanently attached; oral surface somewhat depressed and bounded by a steep peripheral wall.

Thecal plates strongly imbricate, their inner edges curved adorally and their surfaces smooth. Marginal plates of the inner wall elongate, wider than those of the interambulacra and apparently in two alternating rows; those of the inner row a little the smaller. Outer wall made up of very numerous minute thin plates.

Rays five, two solar and three contrasolar. The two solar rays are the right anterior (IV) and the right posterior (V). The cover plates comprise two rows of alternating triangular pieces with apices of the triangles interlocking and directed toward the median line of the ray. Anal pyramid centrally located in the area between I and V.

Dimensions: specimen 3523a has a maximum diameter of 34 millimeters; 3521 is 20 millimeters, and 3522 is 8.5 millimeters in diameter.

Specimens found attached to colonies of a compact multi-lamellar Stromatopora. They have suffered from wear and weather to such an extent that no one specimen shows all the characters and none of them shows the oral plates or the details of the anal pyramid.

It may be noted that this is the first agelacrinite found with two solar rays since Vanuxem described and illustrated *Agelacrinites hamiltonensis* from the Hamilton of New York[22]. From this species ours differs chiefly in having imbricating and unsculptured interambulacral plates. Vanuxem's species has been made the genotype. Since then the genus (also spelled *Agelacrinus*) has been extended to include many species from the Ordovician to the Mississippian. Most of the described forms differ from the genotype, it would seem, by more than specific characters. Strictly interpreted *Agelacrinites* is limited to those forms whose "thecal plates are mosaic, irregular, and sculptured; which have very long and narrow rays and a peripheral band composed of large plates with very small ones at the margin[23]. Meek and Worthen erected a genus, *Lepidodiscus*[24], to include species with "squamous thecal plates,

22 Geol. Third Dist. New York, pp. 158, 306, fig. 80; 1842.

23 After J. M. Clarke, Bull. 49, New York State Mus., p. 193; 1901.

24 Geol. Surv. Illinois, V, p. 513; 1873.

very long narrow rays, and whose peripheral band is very narrow or extinguished and composed of large and small plates; the latter few and projecting on the aboral surface."[25] Other genera and subgenera occur to those familiar with the literature and a revision of the Ordovician agelacrinids is in progress[26]. It appears that *A. hanoveri* partakes of some of the characters of *Agelacrinites* and of *Lepidodiscus* as set forth by Clarke in the quotations given above. A new genus may be necessary for its reception eventually.

Specific name given for Mr. Hanover H. Belanski, who collected the type specimens and donated them to the University museum.

Position and locality.—In Stromatopora reef of the Shell Rock limestone, near Mason City, Iowa.

AGELACRINITES sp.
Plate XLVI, fig. 6.

Description based on an imperfect specimen which preserves very well the marginal plates of the peripheral wall; the plates of the outer ring are small and fine, those of the inner are coarser, alternating, and nearly vertical in position.

The thecal plates and those of the rays are jumbled together in such a way that the turning of the rays can not be determined. On one part of the surface the thecal plates can be seen to imbricate over a small area. The specimen, which is nearly circular, is 20.8 mm. in diameter and the wall is between two and three mm. in height.

Specimen attached to the brachial valve of a coarse-ribbed individual of *Atrypa reticularis* L.

Occurrence.—Cedar Valley limestone; in the coarse-ribbed Atrypa zone, along Lime creek, east of the cemetery, Brandon, Iowa. Collected by Merrill A. Stainbrook.

BLASTOIDEA Say

This extinct class, limited to the Paleozoic, is represented in the Iowa Devonian by one doubtful *Codaster* and by three fine

25 Loc. cit.
26 Bull. Lab. Denison Univ., vol. XVII, p. 400, 1914; also vol. XVIII; 1917.

species of *Nucleocrinus*. The Iowa species are closely akin to those of northern Michigan and of the Milwaukee area but quite different on the whole from those of the Onondagan of the Falls of the Ohio region, a representative of which is the well known *N. verneuili* (Troost). Three species are described herein. However, in Barris' lists[27] an additional species *Elaeacrinus elegans* Hall, is given as one of the rarer forms from the outcrops along the river below Davenport. In the absence of the material which Barris had at hand it is thought that his *N. elegans* was probably a misleading specimen of *N. obovatus*. At the end of his list he cites a number of genera containing undetermined species, among them *Elaeacrinus,* and the unidentified forms doubtless belong to one or more of the Davenport species which are discussed below.

Prof. U. A. Hauber of St. Ambrose College, Davenport, has submitted to the writer a tray of thin slabs from the horizon of *Cystodictya hamiltonensis* below that place and along the river. The slabs contain fragments and crushed specimens of a *Nucleocrinus*. Though their markings suggest *N. obovatus* specific determination can not be made with certainty.

EUBLASTOIDEA Bather

CODASTERIDAE Etheridge and Carpenter

CODASTER SUBTRUNCATUS (Hall).

Plate XXXVI, fig. 15.

1858. *Pentremites subtruncatus* Hall. Geol. Iowa, vol. I, pt. ii, p. 485, pl. I, fig. 4.

1882. *Troostocrinus subtruncatus* Etheridge and Carpenter. Ann. & Mag. Nat. Hist. vol. IX, p. 249 (in a list).

1886. *Codaster subtruncatus* Etheridge and Carpenter. Cat. of the Blastoidea of the Brit. Mus., pp. 132, 265 (in a list).

1903. *Codaster subtruncatus* Hambach. Trans. Acad. Sci. St. Louis, vol. XIII, p. 48.

> "Turbinate or reversed pyramidal, the base round, gradually becoming angular above, distinctly pentangular at the base of the pseudambulacral spaces; base

[27] Proc. Davenport Acad. Sci., vol. VII, pp. 25-27; 1889.

small, almost pointed, apex broad subtruncate above; basal plates small, less than half the length of the body; radial plates less than one and a half as long as the basal plates, slightly divided above for the reception of the pseudambulacral plates; interradial plates small, rising above the centre when complete; summit convex, flattened in the centre; pseudambulacral spaces short, abruptly convex in the middle; poral plates fifteen or more in each series; ovarian apertures small, round."—After Hall, who employed Roemer's terminology.

This unique specimen was obtained by Hall from the shaly limestones of Cedar Valley age in the vicinity of Buffalo (formerly called New Buffalo), Muscatine county, Iowa. The whereabouts of the type is unknown to the writer. Barris[28] thought this species might be identical with *Heteroschisma gracile* Wachsmuth—and judging from Hall's figure there is a strong resemblance. The fact that Barris years afterward listed[29] *H. gracile* among the fossils from the vicinity of Davenport may have been based only on this supposition. In support of this probable conviction on part of Barris, there is in the University of Iowa a lot of *Codaster gracilis* (=*H. gracile*) from Alpena, Michigan, which Calvin secured from Barris; a label accompanying them in Barris' handwriting reads "*Heteroschisma gracilis* Wachsmuth", and "*Pentremites subtruncatus* Hall" is written below as a synonym.

Two views of a specimen of *Codaster gracilis* from Michigan are given for comparison on plate XXXVI, figures 13, 14.

NUCLEOCRINIDAE Bather

NUCLEOCRINUS OBOVATUS (Barris).
Plate XXXVI, figs. 6-9, 16, 17.

1883. *Elaeacrinus obovatus* Barris. Geol. Illinois, vol. VII, p. 358, text fig. 3.

1886. *Elaeacrinus obovatus* Barris. Proc. Davenport Acad. Sci., vol. 4. p. 88, Pl. i, figs. 1, 2, and text fig. 3.

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28 Geol. Illinois, vol. VII, p. 357; 1883; Davenport Acad. Sci., vol. 4, p. 87; 1886.

29 Davenport Acad. Sci., vol. 7, p. 27; 1899.

1886. *Elaeacrinus obovatus* Etheridge and Carpenter. Cat. of Blastoidea in Brit. Mus. p. 216 (in a list).

1903. *Olivanites obovatus* Hambach. Trans. Acad. Sci. St. Louis, vol. XIII, p. 50 (in a list).

1911. *Nucleocrinus obovatus* Cleland. Wisconsin Geol. Surv. Bull. XXI, p. 43, Pl. 3, fig. 2.

"Body obovate or elongate-balloon shaped, more than once and a half as long as wide; upper half wider than the lower, semi-ovoid; greatest width at about two-thirds from the base; lower half gradually increasing in width to the distal end of the ambulacra; base truncate with a deep concavity, which is filled by the column. Cross-section pentangular, with straight or very slightly convex sides, except along the basals, where the sides are somewhat concave, and the section more stellate.

Basals deeply imbedded within the columnar cavity, the outer angles barely reaching the margin. Radials comparatively small; length twice their width at the basiradial suture, gradually increasing upward, so that the forks or limbs at their upper side are about equal in width to the body of the plate at its lower side. The lateral sides are somewhat thickened at the upper face of the edge, more particularly toward the lower end of the plate, where they produce indistinct ridges at the suture lines. The upper side of the limbs is gracefully curved in an upward direction, with reëntering angles toward the lateral sutures, and deeper ones toward the radial sinuses. From the bottom of the plate there extends to the radial sinus (which, in this species, is about half-way to the top of the limbs) a conspicuous rounded ridge, ending in a very prominent lip; and it is this structure mainly which produces the truncation toward the basal region, which otherwise would not be very perceptible.

Interradial or deltoid pieces large, measuring almost four-fifths the length of the body; broad lanceolate. Four of these have a length equal to twice their greatest width. The fifth, that of the posterior side, which in this genus is divided throughout its full length by a large anal plate, occupies, including the latter piece, no greater width than the four regular interradials, and the two halves are narrower at any place than the interposed anal plate. The latter is lanceolate, of nearly equal width throughout, slightly tapering at the upper end. Its lower side rests on the same surface with the other plate, but gradually rises above the general level, and at the top is highly elevated, standing out conspicuously over the adjoining parts. Even in height it extends beyond the limits of the other parts of the body.

Anal aperture large, oval in form, horizontal in position. Toward the outer side, the opening is formed by the wall of the anal plate, which at the upper end is bulging outward without being excavated. The lateral sides of the aperture are formed by the upper curved ends of the interradials, which are connected by two or three small anal vault-pieces, and these constitute the upper boundary of the aperture.

Ambulacra long, narrow, linear, raised above the general level of the body, except close to the oral pole, near which they curve abruptly toward the oral opening, and the ambulacrum becomes located below the abutting surface. The lancet-piece is deeply grooved along the median line, and when the side-pieces (pore-pieces of Roemer) are not in place, there is at the suture, along each side of the plate, a deep sulcus, penetrated by the hydrospire-pores. This sulcus, however, when the side-pieces are *in situ,* is totally filled, and the sides of the ambulacrum rise abruptly above the abutting edges. The side-pieces rest against the upper face of the deeply crenulated ridges of the lancet-piece. They are strongly wedge-shaped and placed obliquely to the ambulacral or food groove, with the smaller angle directed to the aboral side. Their number is from about sixty to nearly ninety in very large specimens. The outer side-pieces (supplementary pore-pieces of Roemer) are comparatively large, their longer side being about two-thirds, their shorter sides fully one-half, of the corresponding sides in the pore pieces.

The summit is a flat disc, somewhat depressed in the middle, sub-pentangular in outline, the angles resting against the slightly truncated upper part of the oral plates, leaving in the direction of each ambulacrum a good sized passage. The central aperture is pentangular, rather deeply depressed.

Spiracles ten, one to each side of the ambulacrum; those of the posterior side not in contact with the anal aperture. They are in this species not easily detected, being placed laterally within the projecting edges of the interradials, which for their reception are at this place more prominent, and somewhat excavated. The hydrospires are arranged in ten groups, with two in each group; they are in form similar to those of *Granatocrinus Norwoodi,* but comparatively a little larger. Hydrospire-pores small, and more or less hidden.

Column of medium size, round, composed at the upper end of high joints.

The ornamentation of the radials consists of indistinct concentric curves sub-parallel with the arched upper surface of the plate. The ornamentation of the interradials, as in most species of *Elaeacrinus,* is sharply divided by two longitudinal lines, the median part (which in position and somewhat in form, at the four lateral sides of the body, corresponds to the large anal plate of the posterior side) is more or less destitute of ornament. The two sides, however, are crowded with rows of small granules, arranged so as to divide the field into narrow parallel spaces, which are transversely arranged, and of the width of the pore-pieces."—After Barris.

In writing the above description, Barris made use of specimens of various sizes, some from Iowa and some from Michigan. He says, "the largest measuring one inch and three-quarters in length, the smallest seven-eighths of an inch." His figure 1, on plate I, is of a specimen fully two and three-eighths inches long. This specimen is now in the Davenport Academy collection and is labelled "Type specimen of *Elaeacrinus obovatus.*" Unfortunately no locality record is given hence we do not know whether this fine specimen is from Iowa or from Michigan. The fact that it is at least five-eighths of an inch longer than the longest which Barris says he used in writing his descriptions leads us to suspect that his figure 1 was entered on the plate after his manuscript had been set up and that the specimen was not at hand when he wrote the description of the species. In other respects than size it conforms quite closely to the description of the types.

Position and localities.—Barris' type specimens are from the "*Spirifer pennatus*" beds of the Cedar Valley stage, near Buffalo, Iowa; from the Cedar Valley near Iowa City; and "from the top of the Hamilton group in the Thunder Bay region of northern Michigan." The most notable locality near Buffalo is west of the village in Barris' "Fifth Ravine" along the valley of Cedar Creek. The small local quarry, which Norton calls Clarke's quarry, has of late years been expanded on a large scale by the Dolese Brothers.

A badly crushed specimen in the Davenport Academy collection is at least 45 millimeters in length. It is tentatively referred to this species.

In Owen's 1852 Report on the Geology of Wisconsin, Iowa, and Minnesota, pages 508 and 625, he mentions finding a specimen of *Olivanites verneuili* at the mouth of the second creek below Rockingham. This village no longer exists but on a map of Iowa dated 1839[30] it is shown on the right bank of Mississippi river opposite the mouth of Rock river, Illinois, and thus not far upstream from Barris' localities for *N. obovatus*. The specimen collected by Owen presumably belonged to the latter species and not to the Onondagan *N. verneuili*, which differs quite markedly from any of our Iowa species.

One specimen in the University collection was found by Mr. Frank Bond in the Cedar Valley limestone between the wagon road and the river and only a few feet above the level of the water a little south of the old Sanders quarry near the north limits of Iowa City. It is not known where Barris found his Iowa City specimens but it is presumed to have been at this horizon.

A slab from Aicher's quarry, in the University collection, bears a small radial or forked plate presumably belonging to this species. It is faintly marked by fine lines which run parallel to its lateral edges. On the slab is also a specimen of *Strobilocystites calvini*.

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30 Map of Surveyed Part of Iowa (18 counties), New York, 1839, published by J. H. Colton.

An incomplete deltoid plate of ellipsoidal shape and of large dimensions was collected some years ago by Dr. E. J. Cable near the base of the Cedar Valley limestone at Littleton, Iowa. The plate preserves the markings unusually well, the median tract is narrow and slightly raised above its surroundings and its surface is subplane or gently concave. The chocolate brown color of the specimen is in striking contrast with the yellowish gray matrix. Length 47 millimeters, greatest width 26 millimeters; the width is thus fully one-third greater than that of any other *Nucleocrinus* at hand. The specimen is number 450, Museum Natural History, Iowa State Teachers College. (See text figure 65.)

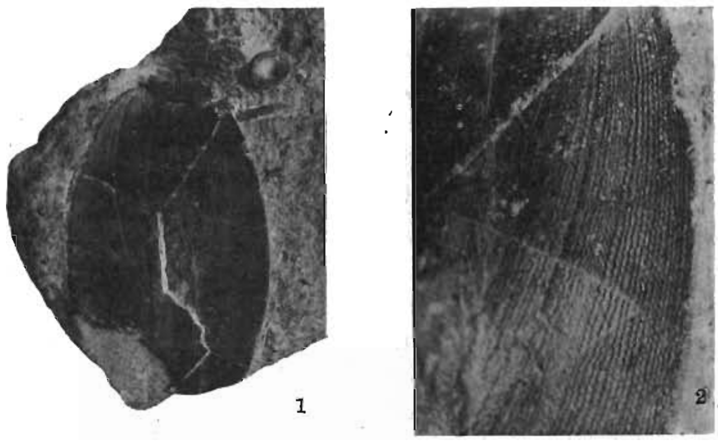

FIG. 65.—Deltoid plate of *Nucleocrinus obovatus* Barris. 1. Natural size, proximal end broken away. 2. Part of surface enlarged about x3, showing the ornamentation. Collected near Littleton, Iowa, by Doctor E. J. Cable.

Three specimens in the collection at the University are from Partridge Point, near Alpena, Michigan, where they were collected by Barris. They have the narrow elongate shape characteristic of this species.

NUCLEOCRINUS MELONIFORMIS (Barris).
Plate XXXVI, figs. 10, 11.

1883. *Elaeacrinus meloniformis* Barris. Geol. Surv. Illinois, vol. VII, p. 361.

1886. *Elaeacrinus meloniformis* Barris. Proc. Davenport Acad. Sci., vol. IV, p. 91, Pl. 1, fig. 3.

1886. *Elaeacrinus meloniformis* Etheridge and Carpenter. Cat. of Blastoidea in Brit. Mus., p. 216 (in a list).

1903. *Olivanites meloniformis* Hambach. Trans. Acad. Sci. St. Louis, vol. XIII, p. 50 (in a list).

"Body small, ovoid, height nearly one-half more than the width; greatest width through the median part, or a little above; curvature toward the two poles nearly equal, but the pole itself at the abactinal side abruptly depressed, and the concavity perfectly filled by the column. Surface of the ambulacra raised but little above the general plane of the body. The plates along the sides of the ambulacra are marked with obscure transverse grooves, bordered at each side by a sharp ridge, which forms along the median portions of the plate a deltoid-like figure. The ridges which join with one end at the summit, with the other at the radial lips, form together around the body a well-marked penta-petaloid figure, in which the ambulacra are placed along the median line; and as the ridges in this species happen to be more conspicuous than the margins of the ambulacra, the ridges appear as the boundaries of the latter. Cross-section along the upper half of the body obscurely decagonal, almost circular, decidedly pentagonal across the lips of the radials.

Basals small, entirely hidden within the columnar cavity.

Radials small, body-part longer than usual in this genus, their lower portions resting within the concavity, whence they bend abruptly in an opposite direction, forming a sharp edge at the end of the body. Length more than twice the width at the basi-radial suture, which is about equal to the width of a limb at its upper side. Sinus very short, enclosing but little more than the lip, which is strongly protruding, and from which a very prominent rounded ridge proceeds to the lower edge of the plate. The upper sides of the limbs are convex, with a reëntering angle above the lateral sutures.

Interradials large, occupying four-fifths of the length of the entire body, divided by two raised lines into three parts, the inner or deltoid part provided with fine granules, the outer part with transverse grooves, which are equal to the number of side-plates in the ambulacra. The anal plate, which divides the posterior interradial, differs in form but little from the deltoid-shaped portions of the other four interradials; it is, however, a little wider, and at the upper end protruding outward. The anal aperture is large, rhomboidal, the opening in an upward direction. It is bordered toward the peristome by two summit plates, which rest against the upper ends of the two sections of the interradial.

Ambulacra linear, comparatively shorter and probably wider than in any other species of *Elaeacrinus;* lancet-piece exposed within the food-groove, but only at the upper end of the plate, its lower half is perfectly covered by the side-plates. There are 36 to 38 side-pieces (outer side-pieces cannot be distinguished in the specimens), with a deep socket to each plate. The hydrospire-pores are only seen when the side-plates are broken away.

Spiracles ten, one to each side of the ambulacrum; slit-shaped, placed, like those of the preceding species, within the projecting lateral edges of the interradials: those of the anal side non-confluent with the anal aperture. The hydrospires are unknown.

The summit (which in both type specimens has been preserved) is composed of but few comparatively thick pieces, which are similarly arranged as in *Elaeacrinus obovatus.* Column round, central perforation very small."—After Barris.

This species is quite distinct from *N. obovatus* in being shorter and proportionally wider, in having the central area of each interambulacrum definitely set off by a sharp ridge on each side, and in having much less prominent ambulacra.

No specimens from Iowa have been seen by the writer but one from Waterfowl Bay, northern Michigan, is at hand, evidently collected by Barris; accompanying the specimen is a note by Barris which says "I presume I made a mistake, I described it as *Elaeacrinus meloniformis* when it is Conrad's *Nucleocrinus elegans.*" Barris' original position that it differs from *N. elegans* "in the more elongate form, in the mode of ornamentation, in having almost straight in place of concave interradial sides, and in less protruding and comparatively shorter ambulacra'' has been generally accepted and in the absence of a series of specimens for comparison *N. meloniformis* is allowed to stand.

Position and localities.—From the shaly limestones of Cedar Valley age in the ''Fifth Ravine'' near Buffalo, Iowa, and from the ''Hamilton group'' at Waterfowl Bay and Thunder Bay, northern Michigan. It has not been reported from the vicinity of Iowa City.

NUCLEOCRINUS BONDI n. s.
Plate XXXVI, figs. 2-5, 12, 18.

Body elongate or balloon-shaped, broadly ovate in longitudinal section, widest just above the middle, sharply stellate in cross section; base truncate and deeply excavate; maximum width about three-fourths the height.

Basals deeply hidden within the columnar cavity. Radials small and short, limbs narrow and rounded distally; from the rim of the basal excavation a strong medial ridge extends outward and downward on each plate forming a lip to receive the distal end of the ambulacrum.

The interradials or deltoids are very large and make up the greater part of the theca; each is composed of three areas, a median lanceolate area and two curved doubly-tapering areas, one on either side separating the narrow median area from the ambulacra. The median tract begins at the reëntrant angle between the distal ends of the radials and terminates in an inwardly bent point at the oral pole with the exception of that in the posterior area. In this interradius the median tract is a separate plate. Its upper extremity protrudes above the oral region and for a short distance below the summit its surface is raised slightly above the areas on its flanks; from this region downward, however, its surface is depressed below that of the side pieces. In each of the other four interradial areas the median tract is likewise depressed throughout its length and its sides are limited by low ridges; in the posterior area the lines limiting the anal plate are on the floor of the sunken area ending below at the crests of the radial limbs; between each of these lines and the transversely decorated portion of the side pieces is a very narrow area which vanishes toward the summit; these two narrow tracts are parts of the surfaces of the side pieces.

Anal opening oval, directed toward the summit depression, its outward border formed by the protruding end of the anal plate and its sides enclosed by the inward and downward curving ends of the interradials and by two or three small dome pieces.

Ambulacra very long, narrow, and elevated on sharp keel-like ridges. At the oral pole they curve abruptly downward passing below the roof plates. Aborally they extend a little beyond the base. Lancet-piece sharply and deeply grooved, and partly exposed. Side-plates small, about 120 on each side in the type specimen. When these are removed a series of transverse grooves are seen on the vertical sides of the lancet-piece at the base of each of which is a hydrospire-pore. When the side-plates are in place, these latter features are covered. No distinction between side-plates and outer side-plates can be made out on the specimens at hand. Summit pentangular, covering plates wanting. Spiracles slitlike, ten in number, one on each side of each ambulacrum, and partly concealed under the proximal ends of the interambulacra; those of the posterior side separated from the anal orifice. Column round and small, not filling the basal cavity.

Ornamentation of the radials as in *N. obovatus*. The interradials bear distinctly different ornamentation on the median tract than on the lateral tracts. On the median tract are curved lines which are parallel to the tops of the radials and which may represent growth stages in the history of the theca. In places the lines are replaced by rows of granules; on a few of the areas are one or more fine longitudinal lines. On the laterals are lines which rise along the ambulacral margin and pass in a curved diagonal path to the edge of the median tract, their inner ends being successively higher and higher along the edge of the inner tract from base to summit. These lines too, seem to represent growth periods in the theca; across these, and directed slightly downward, run lines—one for each pore piece; the whole is arranged so as to produce a graceful cross-hatched pattern on a more or less granular surface.

This species is near to *N. obovatus* with which it is associated in the vicinity of Iowa City. It differs from that species in its greater width and stellate cross section, in the sharply elevated and basally protruding ambulacra, in the consistently sunken median areas of the deltoids, and in the general ornamentation.

This species is close, too, to *N. angularis* (Lyon) from the Devonian of the Falls of the Ohio region of Kentucky and Indiana. *N. bondi,* however, is considerably larger, its deltoid plates are concave throughout their length—not "flattened towards the summit" as in *N. angularis,* described by Etheridge and Carpenter (p. 219), its median tract is more depressed, its ambulacra are narrower and more sharply raised, and as near as can be made out the surface markings are different.

Length of type specimen 39 mm., greatest width 28 mm., length of anterior ambulacrum along its curvature, 48.2 mm., antero-posterior diameter of basal cavity, 5 mm.

Remarks:—A recent communication from Mr. Bond tells of finding of the type specimen and of the joy which Professor Calvin expressed at the discovery. A few weeks later his pupil found a second specimen—the *N. obovatus* mentioned above. Both were given to Professor Calvin who sent them for identification to Mr. Charles Wachsmuth at Burlington. By rare good fortune Mr. Wachsmuth's hand-written note of reply, quoted below, was folded by Calvin and placed beneath the label in the tray which contains the type specimen. It bears no date:

"It is possible that these two specimens belong to different species, the larger differs considerably by its angularity and in the proportions of the interambulacral spaces, in which it resembles *Nucleocrinus angularis* Lyon. The smaller one is in my opinion certainly of new species, and identical with some of the specimens of this genus found at New Buffalo, Iowa, and in the Lake Superior region. Of both localities I have here for comparison a large number of fine specimens, some of them nearly 3 inches long, others smaller. Their width in all of them is scarcely one-half their length, and they all have straight, but little excavated interambulacral walls, only the lanceolate plate at the anal side is toward the anus somewhat protruding.

Mr. Barris intends to describe this species through the Davenport Academy.—C. W.''

The cheironym on the label over the note is ''*Nucleocrinus bondi* Cal.''

Position and localities.—The type specimen was found on the side of the wagon road, between the road and the left bank of Iowa river, a short distance south of the old Sanders quarry near the north limits of Iowa City. The rock here is the Cedar Valley limestone and is fifteen to twenty feet below the zone of *Strobilocystites calvini* found near the same place. The specimen was collected by Mr. Frank Bond, a student of Professor Calvin, about 1878, now at the General Land Office, Department of the Interior. Mr. Bond furnished the author with valuable information concerning the precise locality where this and other specimens were found. It is a pleasure to dedicate the species to him.

Another fine specimen was collected in 1864 by Mr. Anton Linder near the boathouse on his homestead in northeast quarter of the southeast quarter, section 33, township 80 north, range 6 west, about two miles north of Iowa City. This specimen is a part of the Fitzpatrick collection all of which has been most generously made available for this study. A third specimen also in the Fitzpatrick collection was found in the northeast quarter, section 30, township 80 north, range 6 west, along Rapid creek about four miles northeast of Iowa City. The right half of this specimen is imperfectly developed giving it a distorted appearance, and it is wider in proportion to its height than the others; in other respects it is typical. A young specimen, about 18 millimeters long, recently collected by the writer in the *Athyris* zone at Aicher's quarry, about three miles north of Iowa City, is tentatively referred to this species.

CRINOIDEA Miller

CAMERATA Wachsmuth and Springer

MELOCRINIDAE Zittel

A family of monocyclic crinoids which range from Ordovician to Devonian. Well defined interbrachials between the primibrachs and secundibrachs and forming a part of the dorsal cup. Radials in contact all around. Two genera are represented in the Iowa Devonian, stratigraphically they occur in probably the latest beds in which this family is found. The specialization attained by some of the species may be in keeping with their late appearance.

MELOCRINUS NODOSUS Hall
Plate XXXVII, fig. 1.

1861. *Melocrinites nodosus* Hall. Geol. Surv. Wisconsin, Rept. Prog., p. 19.

1881. *Melocrinus nodosus* Wachsmuth and Springer. Rev. Paleocr. II, p. 122.

1895. *Melocrinus nodosus* Whitfield. Mem. Am. Mus. Nat. Hist., vol. I, p. 48, Pl. V, fig. 14.

1898. *Melocrinus nodosus* Weller. Ann. New York Acad. Sci., vol. XI, No. 7, p. 118, Pl. XIV, fig. 6.

1911. *Melocrinus nodosus* Cleland. Wisconsin Geol. Surv., Bull. XXI, p. 38, Pl. 3, fig. 4.

"Calyx pyriform, truncate at the base, sides straight or slightly convex from the tops of the basals to the arm openings; cross-section, as seen from above, exclusive of the nodes, obscurely subpentagonal, greatest diameter at the arm bases. The plates of the dorsal cup ornamented with conspicuous nodes.

Basals four, projecting laterally into more or less prominent nodes, columnar facet large, often somewhat depressed between the nodes of the plates. Radials large, heptagonal and hexagonal, strongly nodose. First costals hexagonal, smaller than the radials, strongly nodose; second costals pentagonal or heptagonal, smaller than the first and less strongly nodose. Distichals smaller than the last costals, higher than wide, free beyond the first pair. First interdistichals hexagonal, as large as the first costals and bearing similar nodes, followed by two smaller nodose plates in the second row, one of which often bears a larger node than the other; in the third row there are two or three smaller plates and above these numerous small plates which lead up to those of the vault. The posterior interradius is not differentiated from the other four.

Ventral disk depressed convex or nearly flat, composed of small polygonal nodose plates of nearly equal size; marked by more or less prominent rounded ambulacral ridges which extend from the arm bases towards the center; and surmounted by the base of a subcentral proboscis whose height cannot be determined.''—After Weller, 1898.

Remarks:—Hall's type specimens were collected from limestone blocks in ''the drift about Milwaukee'' by I. A. Lapham, and at Iowa City by Barris, who presumably obtained the single specimen sent Hall, in the Cedar Valley limestone sometime during his pastorate at Iowa City in 1855-1859. It is a rather remarkable fact that no further specimens have been collected here so far as known although other examples have been obtained about Milwaukee. In Whitfield's republication of the species he has figured one of Hall's types. Doctor Chester A. Reeds of the American Museum of Natural History writes that ''the type specimen of *Melocrinus nodosus* Hall is entered on our labels as having been found near Milwaukee, Wisconsin. A large and a small specimen without arms are represented. We have no reference that one or the other of these specimens was collected in Iowa.''[31] Whitfield's figure is reproduced here. The Milwaukee specimens figured by Weller and by Cleland are considerably smaller than Whitfield's lectotype. This species is mentioned but not described by Wachsmuth and Springer in Crinoidea Camerata, volume I, page 294. Its nearest allies are *M. calvini* from the State Quarry beds of Iowa and *M. gregeri* from the Callaway limestone of Misouri. *M. nodosus* is much more nodose than either of these.

31 Personal communication. February 27, 1922.

MELOCRINUS NODOSUS var. IRREGULARIS n. var.
Plate XXXVII, figs. 2-4.

This variety differs from typical *nodosus* in the arrangement of the plates of the posterior interradius which in the first row has a pentagonal plate, point downward, resting on the shoulders of two basals, followed by a single hexagonal plate in the second row and this by three plates in the next row while above these are a number of smaller plates grading into those of the tegmen. The other four iBr areas have a single large hexagonal plate followed by two plates in the next series, and so forth as in typical *Melocrinus.* In true *nodosus* the posterior interradius is not differentiated. Wachsmuth and Springer[32] say that in the genus *Melocrinus* the anterior radial is hexagonal since it "rests squarely on the anterior basal." The other radials are heptagonal. In the specimen at hand the hexagonal radial is at the base of the left anterior ray; all the other radials are heptagonal. These two irregularities may be abnormalities of an individual and further specimens must be sought before the points can be settled.

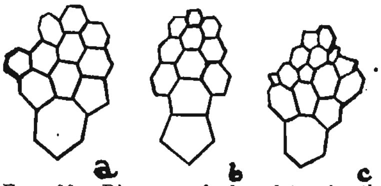

FIG. 66.—Diagram of the plates in the anal interray of three species of *Melocrinus.* Drawn to scale. a. *M. calvini;* b. *M. nodosus irregularis;* c. *M. tiffanyi.* The last is after Wachsmuth and Springer.

Height of specimen 26.3 millimeters, height of arm openings 19.0 millimeters, greatest width 19.5 millimeters, diameter of columnar facet 5 millimeters. Type specimen, number 3600, collected by Merrill A. Stainbrook in the Cedar Valley limestone along Lime creek one-half mile east of city limits of Brandon, Iowa, about ten feet above the *Acervularia davidsoni* reef.

MELOCRINUS TIFFANYI W. and Sp.
Plate XXXVII, fig. 5.

1897. *Melocrinus tiffanyi* W. and Sp. Crin. Cam. N. Amer., vol. I, p. 299, Pl. 22, figs. 7a, b.

"Calyx pyriform; the sides nearly straight from the

32 W. and Sp., Crin. Cam. N. A., vol. I. p. 292; 1897.

top of the basals to near the bases of the arms; the tegmen depressed-hemispherical; cross-section, as seen from above, obtusely pentangular. Surface of plates ornamented by faint ridges, radiating from near the centre of the plates to the centre of adjoining ones.

Basals projecting laterally, forming four conspicuous, elongate nodes; the lower part somewhat excavated for the reception of the column. Radials and costals gradually decreasing in size upwards, about as long as wide; the second costals not more than half the size of the radials. Of the distichals two plates are preserved; the lower one fully one-half smaller than the preceding axillary; the second short, shaped like an arm joint and curving outwards. There are no interdistichals, all plates of the arm trunks being in contact laterally. Interradial areas on a plane with the radials and costals; the first interbrachial the same size as the radials, and followed in the type specimen by two plates at three of the sides, but in the posterior and right antero-lateral interradius by three, and these by numerous rows of from three to four plates, which connect with the disk pieces. Ventral disk depressed-hemispherical, the plates very uniform, rather large, having the size of the third row of interbrachials. They are ornamented like the plates of the dorsal cup, but are a little more convex. There are apparently no orals. Anus excentric, probably connected with a tube.. Arms unknown; column round.''—After Wachsmuth and Springer.

Remarks:—Type specimen which was in the Tiffany collection seems to be lost, at least ''it could not be found at the time of Mr. Tiffany's final illness''[33].

Position and locality.—Cedar Valley limestone, Buffalo, Iowa.

MELOCRINUS CALVINI W. and Sp.

Plate XXXVII, figs. 6-8.

1883. *Melocrinus solonensis* Calvin. History of Johnson County, Iowa, Notes on the Fossils, p. 559 (no description).

1897. *Melocrinus calvini.* W. and Sp. Crin. Cam. No. Amer., vol. I, p. 300, Pl. 22, fig. 6.

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33 Frank Springer, personal communication, Feb. 12, 1920.

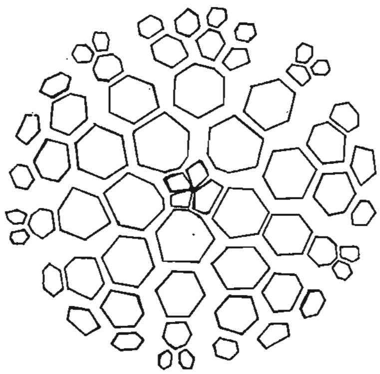

FIG. 67.—Analysis of calyx of *Melocrinus calvini* W. and Sp. Note that the first plate in the anal interray is heptagonal and that it is followed by three plates in the next range.

"Similar to the preceding species, but the sides of the dorsal cup convex, and the general form of the calyx subovoid; the basals less projecting; the radials, fixed brachial and interbrachials—the latter to the third row—crowned by a large, rather conspicuous rounded node without other ornamentation; the upper interbrachial and interambulacral plates a little convex. Basals projecting laterally, and forming four rather conspicuous nodes around the columnar attachment which is a little projecting. Radials and costals longer than wide. The distichals of the same rays in contact laterally. Regular interbrachial spaces large, but slightly depressed between the arm trunks; the plates arranged: 1, 2, 3, 3, the upper ones insensibly connecting with the plates of the ventral disk. Anal interradius widest, having three plates in the second row. Ventral disk short; the plates rather small and of uniform size; orals apparently unrepresented. Anus excentric, probably at the end of a narrow tube."—After Wachsmuth and Springer.

Position and locality.—Type specimen from the State Quarry limestone at Solon, Iowa[34]. It is number 3601 University collection. No further specimens have been collected at any of the State Quarry outcrops; crinoid stems, however, are not rare.

MELOCRINUS (?) LINDERI n. s.
Plate XXXVII, figs. 9, 10.

Calyx conical, width and height about equal; cup expanding gradually from the base, widest just before reaching the arm bases. Dome low, each of its numerous plates bearing a delicate central spinule. The preserved plates of the cup are marked by sharp spinose central nodes but are otherwise smooth.

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34 Geol. Surv. Iowa, vol. VII, p. 78.

Species is nearest to *M. calvini* of the State Quarry beds but is more spiny. In *M. linderi* the iBr and upper plates of the brachial series are sharply nodose while in *calvini* only the radial series bear spiny nodes above iBr_2. Moreover, the type of *calvini* is suboval in cross section near the arm bases, in *linderi* the same section is nearly circular. It resembles also *M. gregeri* but is smaller and narrower than Rowley's type. Better material may prove them identical.

The only specimen at hand is incomplete. It was preserved in a cherty nodule and on its removal the basals and a part of one side were broken off. An area between iBr_1 and the arm bases extending about one-third the circumference of the calyx preserves the surface and shows the spiniferous plates. The remainder of the surface is exfoliated but over this part the outlines of the plates can be distinctly traced. The plan is quite clearly that of *Melocrinus* but the absence of basals makes generic reference a little doubtful.

Position and locality.—In the Cedar Valley limestone at Indian Hollow on right bank of Iowa river opposite the mouth of Turkey creek, section 21, Penn township, Johnson county, Iowa. Collected by Mary Frances Linder for whom the species is named. Type specimen in the Fitzpatrick collection.

Melocrinus belanskii n. s.

Plate XXXVII, figs. 11-16.

Calyx bowlshaped, abruptly spreading, apparently much wider than high, sides convex. Plates smooth, slightly raised, edges depressed making broad grooves along the suture lines; inner surface of plates bearing centrally a cluster of irregular nodes and ridges which are more or less radially arranged. The edges of the larger plates are in some cases delicately milled.

Basals four; they project downward and form a shallow inverted cup with a sharp rim which is deeply notched at the interbasal suture. The plates are subequal, the two on the right being quadrangular, the other two, pentangular. The latter are larger and their outer surfaces slope less abruptly than the former thus deforming in a slight degree the basal cycle and giving the stem a subcentral position.

Radials five, hexagonal, length and width about equal; posteriorly they are separated by a five-sided plate—presumably the anal, thus making six plates in the second cycle. Four of the five radials are much alike in size and general proportions but the base of the fifth (the left posterior) is only about half as wide as the base of the others; morover, the surface of the calyx between this plate and the left anterior radial is considerably depressed. IBr_1 hexagonal, wider than high, each followed by a somewhat smaller pentangular axillary or IBr_2 which is followed by two IIBr of decreasing size. Plates beyond this unknown.

Column round, five millimeters in diameter inside the basal ring; axial canal small, about 0.8 millimeter in diameter, obscurely pentalobate. Associated with the type specimen were several loose plates and numerous fragments and columnals of a large round stem whose side-faces are in some cases ornamented with tubercles. The segments are assumed to belong to this species and a few of them are illustrated.

The presence of six plates in the second cycle is not characteristic of *Melocrinus* but the irregularity in the type specimen here described is regarded as an abnormality. Unfortunately the plates following the anal are lost; it would be interesting to know whether or not the anal was followed by three plates in the range next above as is usual in this genus, or by less than three due to its unusual position.

Troost's genus *Turbinocrinus* (*Turbinocrinites*), proposed in manuscript, has four basals and "the first plate of one of the interradial spaces truncating one of the basal plates"[35], that is, the extra plate is on a level with the radials as in *M. belanskii*. There is some question, however, about the proper interpretation of Troost's specimen[36].

Type specimen collected in southeast quarter section 13, township 95 north, range 19 west, by C. H. Belanski, also the separate fragments mentioned above and referred to this

35 Twenty-eighth Ann. Rept. New York St. Mus. Nat. Hist. (Museum Edition), p. 139; 1879.
36 Wachsmuth and Springer, Crin. Cam. North America, vol. I, p. 294; 1897.

species. Isolated pieces of the stem and plates occur at several stations in the Lime Creek fossiliferous beds near the top of the Iowa Devonian.

STEREOCRINUS Barris.

Barris, Davenport Acad. Sci. vol. II, p. 282, 1878; vol. IV, pp. 102-104, 1886; and Wachsmuth and Springer, No. Amer. Crin. Cam., vol. I. pp. 324, 325, 1897.

Calyx depressed, wider than high, flattened below; basals three, forming a pentagon; RR, hexagonal; IBr, one, pentagonal, axillary; IIBr, two or three; iBr, two, one above the other, the first heptagonal, the second hexagonal, and followed by a range of three. Arms biserial, ten in number, that is, two for each ray; spaces between arm bases depressed. Dome low, pentalobate; anal opening apparently at end of a subcentral tube. Slitlike apertures near bases of arms. Column round.

This genus is found in lower part of Cedar Valley and Upper Wapsipinicon beds of Iowa and in equivalent or somewhat older strata in northern part of southern peninsula of Michigan. Springer has recently described an interesting species of the genus from the Helderbergian of Benton county, Tennessee[37].

STEREOCRINUS TRIANGULATUS Barris.
Plate XXXVIII, figs. 1-3.

1878. *Stereocrinus triangulatus* Barris. Proc. Davenport Acad. Sci., vol. II, p. 283, Pl. 11, figs. 1, 2; also note on page 288.

1881. *Stereocrinus triangulatus* W. and Sp. Rev. Paleocrin., II, p. 127.

1897. *Stereocrinus triangulatus* W. and Sp. No. Amer. Crin. Cam. I, p. 325, Pl. 25, figs. 8a, b.

"Body large; breadth to height as two to one. Basal pieces solidly anchylosed, and either as a narrow rim clings closely to the column or widens into a pentagon, on each side of which rests the first radial. First radials large, hexagonal, the centers of which are con-

37 Springer, F., Bull. 115, U. S. Nat. Mus., p. 15, Pl. V, figs. 3, 4; 1921.

> nected together by ridges, forming a pentagon, the angles of which are equi-distant from the angles of the inscribed pentagon forming the base. Second radials pentagonal, nearly the size of the first radial. First supraradials about half the size of the second radial, pentagonal or hexagonal, resting mainly on the sloping upper side of the second radial, and partly on the interradial, broader than high. The second supraradial, or rather brachial, is of irregular triangular shape, broader than high, whose base is nearly the breadth of the supraradial. First interradial large as first radial, heptagonal, higher than broad. This sustains a second interradial hexagonal, not more than half the size of the first. This is crowned by three small irregular plates, arching from arm to arm, surmounted by another series of three, somewhat smaller. The summit is elevated in the centre. From each series of arms, extending towards the center, is a ridge of larger plates, giving a five rayed aspect to the summit. Plates roughened and tuberculiform.
>
> Proboscis sub-central.
>
> The ornamentation consists of a series of triangles enclosed one within the other, the outer of which—the enclosing triangle—heads in the center of the larger plates, meeting there the apices of as many series of triangles as there are sides of the plates."—After Barris, 1878.

The type specimen was collected in the upper Davenport beds, in bed number four of Barris. It is now in the Museum of the Davenport Academy of Science. Two specimens, numbers 3628 and 3629, in the University collection, are from the Wapsipinicon beds at Solon. They are smaller than the type and are partly exfoliated but enough of the original surface is left to show the characteristic markings. Barris' variety *liratus* has not been seen. Wachsmuth and Springer regard it as not sufficiently distinct for separation. It is apparently a young individual. In the Fitzpatrick collection is a specimen preserving the base of the cup. It shows the smooth pentagon of anchylosed basals, the radials, a few brachials and interbrachials. The characteristic ornamentation is unusually well preserved. (See figure 3, plate XXXVIII.)

STEREOCRINUS LITTLETONENSIS n. s.
Plate XXXVIII, figs. 4, 5.

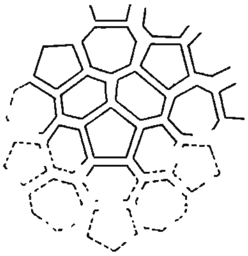

FIG. 68.—Analysis of the plates of *Stereocrinus littletonensis* in so far as they can be made out with certainty. Note the perfect symmetry.

Calyx of about the same width as the type of *S. triangulatus* but shallower. The markings, too, are of the same triangular pattern but are not so prominent. The plates of the cup are further adorned by stout, blunt, central spinelike nodes. Those on the RR are broken off; those on the IBr, IIBr, and iBr plates are directed outward and downward; they are from three to six millimeters in length, and from three to six millimeters in diameter at the base. The raised lines which mark the plates ascend part way up the shafts of some of the "spines." Dome lacking. Stem, large, round.

Type specimen collected among the corals of the *Acervularia profunda* reef in the valley of Dry Run near Littleton, Iowa, by Samuel Calvin[38]. Its horizon is near the base of the Cedar Valley. Wachsmuth and Springer, Crinoidea Camerata, I, page 325, mention having an imperfect specimen of an undescribed species from Waterloo, Iowa. This may well belong to this species since the rocks at the two localities are approximately at the same horizon.

BATOCRINIDAE Wachsmuth and Springer

A family of monocyclic crinoids with three (rarely four) basals followed by five RR and a seven-sided anal plate in the next cycle. Anal plate followed by three plates in the next range. In the subfamily Batocrininae the first IBr is quadrangular, in the subfamily Periechocrininae this plate in most cases is hexagonal. *Megistocrinus* belongs to the latter.

MEGISTOCRINUS FARNSWORTHI White
Plate XXXVIII, figs. 6-12.

1876. *Megistocrinus farnsworthi* White. Proc. Acad. Nat. Sci. Philadelphia, vol. 28, p. 29.

38 Bull. Lab. Nat. Hist., Univ. Iowa, vol. 2, p. 181, 1891-1893.

1881. *Megistocrinus farnsworthi* W. and Sp. Rev. Paleocr., pt. II, p. 138.

Not *Megistocrinus farnsworthi* W. and Sp., Crin. Cam. No. Amer., vol. II, p. 539, Pl. XLVIII, figs. 4a, b.

1904. *Megistocrinus farnsworthi* Wood. Smith. Misc. Coll., vol. 47, p. 64.

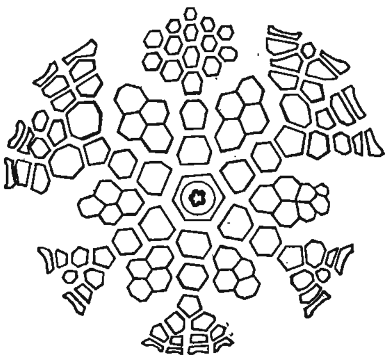

FIG. 69.—Analysis of the calyx of the more perfect of the type specimens of *Megistocrinus farnsworthi* White.

Calyx small for this genus; cup truncate below, the basals depressed, RR in horizontal position; sides of cup gradually spreading to the arm bases. Dome broadly convex and composed of many small tumid plates; anus subcentral and apparently at the upper end of a small tube.

BB three, forming a closely anchylosed hexagonal piece, partly covered by the stem which has a pentalobate lumen. RR five, wider than long, separated by an anal plate which is slightly narrower than the radials and is more nearly hexagonal than heptagonal in shape—the latter being the common shape in this family; upper lateral edge longer than the lower. IBr_1 hexagonal, equal to or larger than the BB, curved, and followed by a pentagonal axillary; IIBr three in the anterolateral rays and but one, a large axillary, in each of the other three; IIIBr form a series of three or four below each of the four arms in the anterior and in the two posterior rays; iBr plates fairly large, the first resting point downward on the shoulders of the RR and followed by a series of two plates and these by a number of smaller pieces. Anal plate followed by three plates in the next rank likewise the suranal is followed by three in the next range, above this there are a number of small pieces to the arm bases. Arms sixteen, four in the anterior ray and in each of the postero-lateral rays, and two in each of the other rays. Arm openings directed upwards.

Plates smooth, margins depressed so as to form wide sutures which are characteristic of this species, except immediately below the arm bases where the depressed marginal areas are still wider and the plates are tumid centrally. Stem round, its proximal columnal but partly covering the basal hexagon. Lumen pentalobate.

The better of the two cotypes is 22 millimeters high and 28 millimeters across the base of the arms, height of dorsal cup 14 millimeters.

Remarks.—White's types, which have not been figured heretofore, are quite distinct from the large thick-plated, high-domed *M. robustus* from Solon, next to be described, which has long been identified under the same name. Calvin extended White's name to include the Solon species, and specimens from Solon were distributed under the name, *M. farnsworthi* White. Wachsmuth and Springer illustrate specimens from Solon and their description of *M. farnsworthi* seems to have been based on specimens from that locality.

Position and localities.—The types of this species were collected in the Cedar Valley limestone near Iowa City by Dr. P. J. Farnsworth. There is one fine specimen in the Calvin Collection from the Cedar Valley beds at Littleton[39]. In the Fitzpatrick collection is a fragment of a calyx slightly larger than the others at hand and in which the basal cycle projects a little beyond the radials—otherwise it is quite typical. It was collected at one of the numerous exposures in the vicinity of Linder's boathouse. Recently, Mr. Walter V. Searight, a student at the University, found a specimen which is almost a duplicate of one of White's types. The specimen was collected along the right bank of Iowa river north of Iowa City in the east half of section 28, township 80 north. Since the precise locality where Farnsworth obtained the types is unknown, Mr. Searight's find is of special interest. Apparently, recognizable calyces are not common.

MEGISTOCRINUS ROBUSTUS n. s.

Plate XXXIX, figs. 1-5.

1897. *Megistocrinus farnsworthi* W. and Sp. Crin. Cam. No. Amer., vol. II, p. 539, Pl. XLVIII, figs. 4a, b.

39 Bull. Lab. Nat. Hist., Univ. Iowa, vol. 2, p. 183, 1891-1893.

Calyx large, robust, mature specimens coarse and thick-plated. Base truncated, hollowed out centrally. Dome strongly convex to conical and quite as high above the arms as the arms are above the base; dome plates tumid, smooth, fairly large and separated by distinct sutures; above the arm bases are strong ridges which extend well up on the dome of most specimens giving the vault a radially fluted appearance. Anus subcentral and apparently at the end of a strong tube.

Arrangement of plates much as in *M. farnsworthi* but with a larger number of pieces in the anal interray. Basal hexagon almost wholly obscured by the stem. RR horizontal in position, anal smaller and narrower than the other plates of the radial cycle. The IBr and iBr_1 plates larger than the radials, the first IBr bent upward at the angle of cup's base.

Arms sixteen (a few with but fifteen), bases protruding strongly and on most specimens the protrusion is greater on one side giving the calyx a lopsided aspect. Arm openings directed outward and slightly upward.

Plates of cup thick and swollen except those of the radial cycle which are flat and smooth and with flush edges; the broad depressed margins of the plates above the radials result in wide sutural grooves.

The type, number 3604, is 43 millimeters in height and 51 millimeters in greatest breadth at base of arms.

Remarks.—An occasional specimen in the lot referred to this species has a rim at the arm bases which is the result of the extension of the iBr and domeplates into the areas between the arms. Other specimens have rather low nodes on plates of the cup and the plates up near the arm bases are faintly nodose, in this respect approaching *M. fitzpatricki.*

Position and localities.—The type locality is near Solon where the abundance of crinoidal remains in the lower strata of the Cedar Valley led Calvin to call them the "Megistocrinus beds." Occasional specimens have been collected at Aicher's quarry and a few at Linder's boathouse, both places along the river north of Iowa City. Several specimens have been found along Rapid creek in sections 20 and 21, township 80 north, range 5 west, and on down the creek through range 6 west. In the Calvin collection is a worn specimen from Dry Run near Littleton; it is tentatively referred to this species. There is a small but quite perfect specimen from Linder's boathouse in the Fitzpatrick collection.

MEGISTOCRINUS FITZPATRICKI n. s.
Plate XXXIX, figs. 6, 7; plate XLVI, figs. 10, 11.

Species based on eight or ten specimens of more or less perfect calyces the largest of which has no tegmen but a well preserved dorsal cup. This is made the type. The general plan of the plates, so far as they can be determined, is close to that of *M. farnsworthi*. The calyx is of moderate size, the cup is broadly bowl-shaped, the tegmen is low and gently convex. Lower part of cup flattened as far as the first primibrachs above which the sides are inflated as far up as IBr_2 or $IIBr_1$. From here the cup contracts slightly to the arm bases, where it is again a little expanded. Height of arm bases a little less than one-half the width of the cup. The greatest width of the type specimen is five centimeters and is taken at the level of the lower edge of $IIBr_1$.

Base hexagonal, hidden by the proximal stem segment. Six plates in second cycle all hexagonal, wider than long—in the type the anal and the two contiguous radials are smaller than the other three. IBr_1 hexagonal, IBr_2 pentagonal and axillary, the area of each nearly the same as that of the radial below; the last IBr is followed by two plates in the next series, those whose sutures can be traced being five-, six-, or seven-sided. Above these secundibrachs the succession is obscure.

Interradial areas characterized by a large hexagonal iBr, longer than wide. This is followed by two plates in the next series, the most of which are six-sided, though five- or seven-sided ones occur. Beyond these the succession is obscure.

The stem is strong, round, and has a large lumen. In the type it is subcentral in position and as a result of this asymmetry the anterior part of the cup bears larger plates than the posterior part as indicated above.

Arms sixteen, tending to be paired, bases protruding slightly.

Tegmen low, made up of small, smooth plates; anus subcentral and evidently at upper end of a short tube.

The surface of the calyx is finely granulose; toward the edges of the plates the granules grade into fine elevated ridgelets which meet the sutures at right angles; each plate is marked centrally by a low but distinct node; the margins of each plate are abruptly elevated in such a way that the common contact of two plates forms a definite ridge along the suture line. The granules, central nodes, and sutural ridges become weaker distally and practically disappear before reaching the arm bases.

The species differs from *M. robustus* in the more evenly rounded bowl-shaped cup, in the markings of the plates, and in the elevated rather than depressed sutures.

Position and localities.—The specimens studied were collected near Linder's boathouse about two miles north of Iowa City by Professor T. J. Fitzpatrick to whom the species is dedicated. A band of dark limestone three to six inches thick, a few feet above where *M. fitzpatricki* is said to have been collected, is filled with segments of a very large crinoid stem, some of which reach a diameter of sixteen millimeters. No other recognizable parts of a crinoid have been found in this layer. (See figure 7, plate XLVI.)

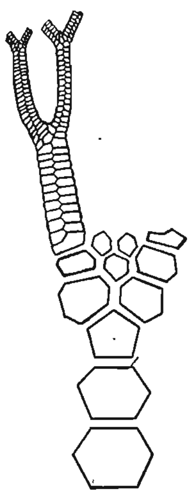

FIG. 70.—Plan of left anterior radial series and of part of the arm of the type specimen of *Megistocrinus clarkei.*

MEGISTOCRINUS CLARKEI n. s.

Plate XL, figs. 1-8; plate XLVI, fig. 9.

A large subglobose calyx with truncate base, somewhat depressed centrally. Sides of cup broadly rounded, widest at arm bases in all specimens observed but one—this reaches its greatest width three or four millimeters below the arms. Dome strongly convex and fully as high as the dorsal cup. Specimens silicified and as a result some of the sutures are entirely obliterated, others are quite distinct, while on parts of nearly every calyx are irregular areas on which the plates are smooth as if polished and where the sutures are readily traceable.

Arrangement of plates as in typical species of this genus; the primibrachs and first interradials are fully as large as the radials. The anal plate is a little smaller than the radials and is followed by a six-sided suranal which is flanked on either side by a large iBr; above the suranal is a vertical series of three or more plates in continuous succession—the whole anal interray, up to the level of the arms, containing twenty to twenty-five plates.

Dome composed of a large number of small polygonal plates and of even contour except for low ambulacral ridges just above the arm-bases; anus subcentral, consisting of an oblique opening through the tegmen and directed toward the center of the dome, its rim smooth, slightly thickened, and raised except on the proximal edge.

Plates of cup smooth, dome plates slightly granular on a few specimens; between the radials and adjoining plates the sutures are a little elevated, as in *M. fitzpatricki;* above these the edges of the plates are flush except on parts of the dome where the sutures are a little grooved. A faint central node marks the IIBr, and IIIBr, and also the iBr plates of the upper part of the cup.

Arms sixteen, rather weak, directed outward and upward in a sharp curve; biserial throughout, branching dichotomous and frequent; eleven to thirteen pieces on each side between base of arm and the first bifurcation, sixteen to eighteen between the first and second bifurcation, above this unknown. Pinnules small and slender, and conspicuously jointed about one millimeter above the base of each.

Stem round, fairly stout; lumen large, pentalobate.

This species has been repeatedly identified as *M. farnsworthi;* it differs from it, however, in its larger size and more globose calyx, in having smooth plates without grooved sutures, especially in the lower cup, and in the absence of an anal tube —in the last respect it differs from all the members of the genus in our area.

This crinoid is already well known[40] to paleontologists from

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40 Clarke, J. M., "Beginnings of Dependent Life": Adv. sheets Fourth Ann. Rept. Director Sci. Div., p. 23, text figs., Albany, New York, 1908.

the fact that it habitually harbored a large parasitic limpet; their consociation was discussed by Clarke many years ago and again more fully in a recent publication[41]. This gastropod attached itself to the tegmen of the crinoid in such a way as to keep the anterior part of its round-mouthed shell over the anal aperture of its host. Its purpose obviously was to feed upon such refuse matter as the crinoid eliminated from its alimentary canal. That its attachment was a permanent one and not casual is proved by the perfect adaptation of the margin of the snail's shell to the irregularities of the crinoid's vault as shown in the illustrations. The smooth round dome and the absence of an anal tube as found in other species favored the establishment of the parasite while the weak, slender, and well separated arms of the crinoid made approach the easier. Of the calyces at hand, fourteen of them preserve the tegmen sufficiently well to be examined for traces of the snail's occupancy; of these eight, or over fifty-seven per cent, show that they were unquestionably the unhappy hosts of a weighty and persistent parasite. These figures illustrate most convincingly how completely fixed had become the association of this crinoid and its dependent snail, *Platyceras*. This genus of snails is not common in the Iowa Devonian; a few specimens have been found in the Cedar Valley mainly near Solon and also at Linder's boathouse north of Iowa City, but not one of them has ever been reported attached to a crinoid and no free specimens have been collected which are similar to the parasite[42] under discussion.

The preservation of this species is worthy of brief comment since it is our only silicified crinoid, except the holotype of *Melocrinus linderi;* in the horizon where it occurs, however, nearly all the associated fossils are thus altered and there is considerable chert with the limestone. The rough, silicified plates of the crinoid show pitted centers about which are ar-

14 Clarke, J. M., "Organic Dependent and Disease," p. 71, fig. 58, New Haven, 1921.

42 *Platyceras inoptatum* n. s. A robust, capacious, holostomatous shell, abruptly expanding from a small dextrally coiled apex. Aperture broadly oval to nearly circular, its margin conforming to the irregularities of the test of the host. Shell marked by numerous crowded lines of growth. Length of shell along curvature from front margin to apex, six centimeters; from posterior margin to apex, one centimeter; antero-posterior diameter of aperture, 31.5 millimeters, transverse diameter of aperture, 28 millimeters. Type attached to specimen number 3623.

ranged rudely concentric rings of siliceous matter. The outer surfaces of the smooth plates are but thin, siliceous shells supported by vertical partitions along the suture lines; when the surfaces of the smooth plates break away the appearance is similar to that of the prismatic ends of favositoid corallites. Among the specimens at hand are four or five large globose balls of cherty matter about twice the size of the average calyx. On the surfaces of these are the plates of the cup and dome, their relative positions and orientations still rudely preserved but all separated and held fast in their places in the cherty chalcedonic mass which apparently originated in the interior of the calyces.

It is a pleasure to dedicate this species to Dr. John M. Clarke, state paleontologist of New York, whose masterly studies of the forms of life in the Paleozoic have a wide bearing which extends far beyond the field of academic speculation.

Position and locality.—About the level of the *Acervularia profunda* zone near the base of the Cedar Valley limestone at Waterloo, Iowa. The specimens were found in some small abandoned quarries on the west side of Cedar river near the south line of the city limits and but a few blocks from the stream. They were obtained many years ago by Mr. and Mrs. David Brant, enthusiastic collectors of natural history specimens. Four specimens, including the one illustrated by Clarke, were given by them to Professor Calvin. Recently Mrs. Brant generously turned over the remaining specimens to the writer for study. Unfortunately that part of the city where the specimens were found has now been largely built over and the original location is covered up.

MEGISTOCRINUS LATUS Hall.
Plate XLI, fig. 1; plate XLV, fig. 3.

1858. *Actinocrinus* (*Megistocrinus*) *latus* Hall. Geol. Surv. Iowa, vol. I, pt. II, p. 480, Pl. I, figs. 1 a, b.

1881. *Megistocrinus latus* Wachsmuth and Springer. Rev. Paleocr., Pt. II, p. 138 (in a list).

1897. *Megistocrinus latus* Wachsmuth and Springer. Crin. Cam. N. A., vol. II, p. 538, Pl. 48, figs. 3 a, b.

1904. *Megistocrinus latus* Wood. Smith. Misc. Coll., vol. 47, Pt. II, p. 66 (in a list).

> "A large species. Dorsal cup short, about twice as wide as high, abruptly depressed at the bottom; the sides expanding upwards; arm bases slightly projecting; plates flat and without ornamentation; suture lines grooved.
>
> Basals closely anchylosed, rather large, located at the bottom of an inverted cup, which is a little wider than the column. Radials about as wide as long; their lower ends abruptly curved to form the sides of the basal concavity, the other portions spreading horizontally and constituting the bottom of the calyx. First costals generally longer than the second. Distichals in the antero-lateral rays three, supporting two arms; the other rays have a single axillary, followed by several palmars with four arms to the ray. Interbrachials: 1, 2, 3, 3, and some small pieces between the arm-bases. The first anal plate, which is a little narrower than the radials, is succeeded by three plates, and these, by numerous irregularly arranged pieces, which decrease in size upwards. Interdistichals one or two, placed longitudinally. Ventral disk hemispherical; the plates nearly flat and of irregular arrangement; orals and radial dome plates a little larger and convex. Anus subcentral. Column strong, the axial canal large and obtusely pentangular."—After Wachsmuth and Springer, 1897.

Horizon and locality.—A single specimen of this large crinoid, lacking the dome, was collected near Iowa City by Mr. L. P. Elliott. It was found in the Cedar Valley limestone and its horizon may be a little higher than that of Hall's type from Buffalo or that of Wachsmuth and Springer's specimen from the Tiffany collection. Udden reports this species from the *Spirifer parryanus* zone of Muscatine county[43].

Two imperfect calyces from the type locality were recently collected by the Reverend Mr. Hauber of St. Ambrose college.

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[43] Iowa Geol. Surv., vol. IX, p. 282; 1899.

They show well the large smooth radials and other plates characteristic of the species. A calyx collected by the writer near North Liberty, mentioned above under localities of *Strobilocystites calvini,* further extends the distribution of the species.

Remarks.—The Iowa City specimen when found was covered with a coating of hard foreign material, the removing of which obliterated the surface characters of the plates. Posteriorly the cup turns abruptly upward resulting in a reduction of the number of plates and other abnormalities. Four of the radials are normal hexagonal plates, the other two, posteriorly situated, are one smaller and one larger than the others and are five- and seven-sided respectively. Neither is followed by the proper succession of plates but a study of the three anterior radial series brings out the proper orientation and it is found that the small pentagonal plate followed by two hexagonal pieces in the next range and these by a number of smaller pieces is the anal. The heptagonal radial is right posterior in position and is followed by a pentagonal plate and this by two fairly large plates in the same range.

Megistocrinus nodosus Barris.
Plate XLI, figs. 2-4.

1878. *Megistocrinus nodosus* Barris. Proc. Davenport Acad. Sci., vol. II, p. 285, Pl. 11, fig. 4.

1881. *Megistocrinus nodosus* Wachsmuth and Springer. Rev. Paleocr., Pt. II, p. 138 (in a list).

1885. *Megistocrinus nodosus* Barris. Proc. Davenport Acad. Sci. vol. IV, p. 98, Pl. 1, fig. 8; Pl. 2, fig. 2.

1897. *Megistocrinus nodosus* Wachsmuth and Springer. Crin. Cam. N. A., vol II, p. 541, Pl. 49, figs. 5 a, b.

1904. *Megistocrinus nodosus* Wood. Smith. Misc. Coll., vol. 47, II, p. 65.

> "A large species. Dorsal cup broadly urn-shaped, the truncated part embracing basals, radials, and first anal plate, which are in about the same plane; the sides of the cup which rise from the lower end of the first costals, slightly convex, expanding near the arm

bases. Plates without ornamentation; but the costals and interbrachials of the two proximal rows are somewhat nodose, while the radials are slightly convex, and the distichals and upper interbrachials almost flat.

Basal disk but very little projecting beyond the column, the columnar facet excavated and surrounded by a well defined circular rim. Radials and costals increasing in width upwards; the radials longer than wide; the costals wider than long. The highest orders of brachials arranged as in preceding species (*M. depressus*). Arms sixteen from the calyx; long, slender, bifurcating, and composed of a double series of interlocking pieces. First interbrachial as large as the first costals; followed by three or four rows of two plates each. First anal plate succeeded by 3, 4, 4, and 3 plates. Interdistichals two to three. Tegmen highly convex, somewhat inflated posteriorly, the interradial and interaxillary spaces deeply grooved from half way down to the arm regions; the posterior groove broadest and deepest; the surface paved by numerous irregular pieces, among which the orals are larger, subspinous, and not in contact; the radial dome plates strongly nodose. Anus subcentral. Column large."—After Wachsmuth and Springer, 1897.

Position and localities.—Barris' specimens were collected both at Alpena, Michigan, and near Davenport, Iowa. A very large example, partly embedded in a tough matrix, was collected at Cook's quarry in Davenport, in the Cedar Valley limestone. On this specimen the nodes are considerably larger and extend farther up on the calyx than they do on most of those from Alpena. The Cook quarry specimen is in the collection of the Davenport Academy of Science. Barris' type specimen, also collected at Cook's quarry and described in the Davenport Academy Proceedings, volume II, has not been studied by the writer. It is not with the other specimens at the museum.

MEGISTOCRINUS MERRILLI n. s.
Plate XLV, fig. 7.

Species based on the basal parts of a calyx preserving three cycles of plates. BB three, united, forming a hexagon, and not projecting as a rim around the stem facet. RR five, hexagonal, wider than long, except the plate assumed to be the right posterior radial and the anal whose widths and lengths are nearly equal. This cycle of plates is horizontal in position. IBr averaging a little wider than long and increasing in width distally; the suranal and iBr plates longer than wide, the latter resting point downward on the shoulders of two radials. All plates in the second and third cycles are hexagonal. The third cycle plates are bent gently outward and upward about their midlength thus giving the calyx a broad flat base. Plates smooth, sutures flush; a low round central node is present on each of the plates of the third cycle. In diameter the node is from one-fourth to one-third the width of the plate. Each plate of the second cycle bears a shallow median depression. In the same zone and near the same place was found a large calyx whose cup is broken and considerably exfoliated. Its arm bases are strong and well separated; the plates near the base of one arm and a part of the dome are preserved well enough to show that they are not nodose. This specimen (No. 3766) may belong to the same species but the evidence is only circumstantial.

This species approaches *M. nodosus* but the latter has convex rather than depressed RR, its third cycle of plates is nearly vertical in position, and its RR are longer than wide. Some of the free plates assigned to *Megistocrinus pernodosus* from east of Brandon are somewhat similar to the nodose plates of the third cycle of this species but in *pernodosus* they are stouter and in nearly all cases they cover more of the plate.

Position and locality.—Cedar Valley limestone, *Acervularia profunda* zone, 1¼ miles southwest of Brandon, Iowa. Collected by and named for Mr. Merrill A. Stainbrook.

MEGISTOCRINUS PERNODOSUS n. s.
Plate XLI, figs. 5-23.

Species known from disconnected plates and pieces of stems all closely associated in a narrow shaly zone. Fortunately several sets of anchylosed basals are in the lot—to one of these basals is attached a single radial.

BB three, of equal size, forming a hexagon with sides alternately long and short; plates closely anchylosed but the interbasal sutures are distinct; axial canal large, pentalobate.

RR hexagonal, extending horizontally and slightly downward suggesting a moderately broad and excavate base; the attached radial bears a strong transverse node which lies across the plate and is crescentic-oval or reniform in cross section, the distal side being convex and the proximal gently concave; several loose plates in the collection are identical with this one and are assigned to the same position in the calyx. A few of the plates are bent similar to IBr_2 in the cup of *M. robustus* suggesting a sharp upturning of the sides of the calyx.

The loose plates occur abundantly; they are thick, heavy, and polygonal—mainly hexagonal or pentagonal—and each bears a large prominent node which is smooth and of varying contour. In some cases the nodes are quite round, high, and centrally placed, in others they appear as thick swellings that cover the

FIG. 71.—Nodose plates and stem segments of the crinoid *Megistocrinus pernodosus*. The left figures in the second and fourth rows illustrate by comparison the minimum and the maximum amount of surface covered by the nodes. Stem segments show the usual features of the joint face as well as the peripheral nodes. Enlarged.

whole plate and conform to its general outline; on several plates the nodes are noticeably constricted at their bases and in a few cases a low platform surrounds the node base. The height of a node is variable but in most cases it is fully one-half the diameter of the plate which bears it; on some of the smaller plates, possibly iBr or dome plates, their height is fully equal to or greater than the plate diameter. The edges of all plates are marked by an intricate pattern of low labyrinthine ridges which are conspicuous under a lens, especially on somewhat weathered specimens.

Accompanying the plates are abundant columnals and pieces of a large, round—rarely subpentagonal—stem presumably belonging to this species. In these the lumen is small and pentalobate and surrounded by a sharply elevated rim rising from the central area on both joint-faces of the columnal. The floor of the central area immediately surrounding the rim of the lumen is so thin as to be translucent. Some of the columnals bear a circlet of low peripheral nodes on their side faces. Short pieces of the stem are characterized as a rule by having alternate columnals wider and thicker; the side faces of the thicker columnals are not parallel to the axis of the stem but are bevelled in such a way that they have a large and a small circumference; the row of encircling tubercles follows the major circumference.

Remarks.—Judging from the abundance of detached plates and stems this species was very common at the horizon throughout which it is found. The calyx evidently is large and has a broad truncate base attached to a strong stem. The highly nodose character of the plates is more marked than in any other species of the genus and reminds us of those of *Melocrinus nodosus irregularis* of the same locality and at nearly the same horizon. The six-sided base, the horizontally placed radials, and the large size of the plates and stem columnals make reference to *Megistocrinus,* however, reasonably safe. *M. concavus* Wachsmuth is another Devonian crinoid with knobby plates. It has not been reported from Iowa but does occur with *M. nodosus* and others at Alpena, Michigan. The radials, however, of *M. concavus* are not nodose and none of the specimens at hand or of the published illustrations shows transverse nodes such as are present on the radials of *M. pernodosus*.

Position and localities.—Limestone beds of the Cedar Valley above the coral reef along Lime creek, Buchanan county, and at the same horizon in the interurban railway cutting east and south of Brandon, Iowa. About forty rods north of the Brandon cemetery and west of the diagonal road in southwest quarter, section 23, township 87 north, range 10 west, is a small gully which leads down to Lime creek. The floor of the gully for some distance is in limestone rock the upper stratum of which is a crinoidal layer six to ten inches in thickness crowded with stem segments and the nodose plates of this or of a similar species. A long search yielded no calyces.

HEXACRINIDAE Wachsmuth and Springer

A family of monocyclic crinoids which is very common in the Devonian of Europe but is rather sparse in the American Devonian. BB three or two, forming a hexagon; RR five, separated posteriorly by an anal plate. Represented in the Iowa Devonian by three species of *Hexacrinus* and by one of *Arthracantha*.

Hexacrinus occidentalis W. and Sp.
Plate XLII, fig. 1.

1897. *Hexacrinus occidentalis* W. and Sp. Crin. Cam. No. Amer., vol. II, p. 745, Pl. 78, fig. 10.

> "A small species. Dorsal cup higher than wide, broadly truncate at the base, very gradually spreading to the arm bases; the sides a little convex; the plates moderately thick and without ornamentation; the suture lines indistinct.
>
> Basal cup projecting laterally in form of a rim; its lower face slightly excavated for the reception of a large stem. Radials about one-third longer than wide, a little wider at the top than at the bottom; facets for the reception of the costals about two-thirds the width of the plates; semicircular, and somewhat thickened at the lower margin; the limbs but slightly truncated. Costals two, forming a syzygy, the lines of union ob-

scure; the hypozygal joints very short and subquadrangular, the epizygal, of which the lower part is placed within the facet, considerably longer and pentangular. Arms ten; stout, cylindrical, composed throughout of rather long, single joints, of which the upper and lower faces are parallel; the main trunks giving off armlets, one from each fifth or sixth joint, the intervening joints pinnule-bearing. The armlets extend to the same height as the main arms, but have only half their width. Both are composed of quadrangular joints, which are somewhat shorter than wide; while the pinnules are short, and their joints fully twice as long as wide. Armlets and pinnules are borne only on one side of the arms: in the anterior ray from the inner side, in the lateral rays from the outer one. There is but one interbrachial plate, but this was apparently followed by several rows of small, nodose, interambulacral pieces. Form and position of anus unknown. Column round; the nodal joints considerably widest, and distinctly rounded at their edges."—Wachsmuth and Springer, 1897.

Remarks.—No additional specimens of this species have been found so far as known. The type is in the Davenport Academy of Science. Owen[44] mentions finding four crushed specimens of a *Hexacrinus* in an encrinal layer about fifty feet above the river in Le Claire's quarry at Davenport. This is the same quarry, according to Barris,[45] at which the type specimen was collected. The type is firmly attached by one side to the matrix and the arms and pinnules are in place. The latter, as noted above, are given off only on one side of the arms while in ordinary crinoids they "are arranged alternately on opposite sides from every second joint." (Crin. Cam. N.A., I, p. 81.) The only American species of this genus occurring beyond Iowa is *Hexacrinus leai* (Lyon) from the Hamilton at Louisville, Kentucky.

Position and locality.—Cedar Valley, "*Spirifer pennatus*" beds, Le Claire's quarry, Davenport, Iowa.

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44 Geol. Surv. Wisconsin, Iowa, Minnesota, pp. 507 and 625; 1852.
45 Proc. Davenport Acad. Sci., vol. VII, p. 20; 1899.

HEXACRINUS SPRINGERI n. s.

Plate XLII, figs. 2-9; plate XLIII, figs. 1-9.

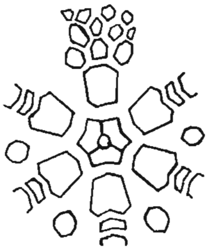

FIG. 72.—Plan of *Hexacrinus springeri.*

Calyx medium size. Cup higher than wide, base truncate and a little excavate; sides gently convex except the left which is flattened in the type, expanding gradually upward but rather abruptly in passing from the basal to the radial cycle; the plates thick and unornamented; the suture lines at bottom of distinct and deep grooves. BB projecting below in a distinct rim which is only slightly notched by the prominent interbasal sutures; plates not anchylosed. RR longer than wide and a little wider above than below; surface of each plate elevated medially into a broad indefinite ridge which continues up over the IBr; facet for receiving IBr_1 broadly curved and the distal edge thickened at the center of the plate; limbs short and sloping downward. Anal plate with subparallel sides, flatter than the RR, followed by 3, 4, and 4 polygonal pieces, those of the first row about as large as iBr of the other interradial areas. IBr, two, the first quadrangular, a little more than twice as wide as long and extending the full width of the facet, the second pentagonal, distinctly separated by a suture and not forming a syzygy; IIBr small, quadrate, in contact laterally; iBr_1 fairly large, at least eight-sided and apparently followed by two pieces in next range. Arms two to each ray, apparently uniserial; dome and anus unknown. Stem facet round, opening through the basals 1.5 millimeters in diameter.

Remarks.—It is a pleasure to dedicate this fine species to Doctor Frank Springer whose scholarly treatises on North American crinoids have been sources of information and inspiration to every student of this fascinating class.

The type specimen is 13.8 millimeters high from the base to the top of IBr_2 of the left anterior ray; antero-posterior diameter at top of radials 13.6 millimeters. Separate plates of this species are common at the horizon in which the type was found. Several of the plates, while identical with those of the type, indicate that they belonged to individuals of considerably greater size. The type was collected by Mr. C. H. Belanski, and is in the University collection.

Position and localities.—In the Shell Rock limestone on the left bank of Shell Rock river in Floyd county, in the northwest quarter of the northeast quarter, section 4, township 95 north, range 18 west. The *Hexacrinus* zone is only a few feet above the level of the river and can be traced more or less continuously north to Nora Springs and south to Rockford. Separate plates as noted above have been found at several outcrops along the river.

HEXACRINUS IOWENSIS n. s.
Plate XLII, figs. 10-13.

A small species, represented in the collections by two calyces which preserve only the BB and RR. Cup expanding gradually, width at top of RR greater than the height at this level; base truncate, flattened or but slightly excavate; the plates fairly thick and ornamented; suture lines distinct and at bottoms of shallow grooves.

BB three, projecting below to form a sharp rim which is slightly notched by the interbasal sutures. In one of the two specimens one of the BB is much larger than either of the other two, is six-sided and supports two RR and on its shoulders half the base of the RR lateral to these; the other two BB are four- and five-sided. In the other specimen the three BB are of nearly equal size. RR a little wider above than below, their sides subparallel, width to length variable, some longer, some shorter than greatest width; IBr facets rounded, shallow, and thickened at the center of the margin. Plates above RR unknown. Column facet round, small; opening through base very narrow.

The ornamentation consists of a number of low ridges or rows of nodes which are parallel to the upper edges and shoulders of the BB, and to the lower edges and sides of some of the RR. In addition low nodes are indiscriminately scattered over the surface of each plate.

The specimen with the normal Hexacrinid base is made the type. On this the ornamentation which parallels the sutures is the dominant type and though nodes are present they are not as prominent as on the specimen with the irregular base. Type and cotype are in the University collection.

Remarks.—This species is the first American representative of the genus in the Devonian whose plates are ornamented. Complete calyces are awaited with interest.

Position and locality.—This interesting little species was collected by Mr. C. H. Belanski at a small outcrop in the Shell Rock limestone in a gutter along the wagon road on the east side of Shell Rock river in Floyd county. The precise locality is in the southwest quarter of the northwest quarter of section 28, township 96 north, range 18 west. Separate plates also occur at this horizon at several points for some miles up and down the river. Though occurring with *H. springeri* the separate plates are readily distinguished since those of *H. iowensis* are ornamented.

ARTHRACANTHA MAMELONIFERA n. s.

Plate XLII, figs. 14-18.

Species known only from incomplete plates which bear the tubercles characteristic of this genus. One plate, a radial, is the most perfect. Its upper face bears the curved facet for the reception of the IBr; the center of the facet protrudes outward as a thin lip, and its floor slopes inward; the limbs are short. About a millimeter of the upper margin of the plate is thin, nontuberculate, and depressed; below this area the surface is abruptly elevated—mostly so along the mid-line—and the plate is thicker. On this shoulder the tubercles are more or less crowded and irregularly arranged but become fewer and farther apart proximally. Each tubercle closely resembles those on small echinoid plates: at the top is a circular foramen-like pit which served as a socket for the movable spine; around the pit is a mamelon-like border and in many cases the "neck" of the "mamelon" is slightly undercut. The largest tubercles are those toward the center of the plate. These are from one to one and a quarter millimeters in diameter, while the average tubercle is a little over half this and the average height is close to one-half millimeter. Sixteen tubercles are present on the plate and doubtless a few are missing along with the proximal border which is broken off.

Among the tubercles and even on their sides are small granules and a strong lens will show among these still another series decidedly smaller and finer and quite numerous. The inner surface of the plate is smooth and concave.

Remarks.—Careful screening of the shale in which the plates are found has not yielded any undoubted spines. It is thought that the spines were much larger and coarser than those of any described species of *Arthracantha.* Incomplete plates have been found at three localities. At each of these there occur abundant segments of a small round stem with a small lumen, but since a flexible crinoid occurs in the same bed it is not certain that the stem segments are to be associated with *Arthracantha.* It should be noted that this is the first western occurrence of this genus—all its species heretofore having been found in the vicinity of Lake Erie.

The writer wishes to thank Miss Winifred Goldring of the New York State Museum at Albany for identifying these plates as those of *Arthracantha.* Miss Goldring's forthcoming monograph on the Devonian Crinoids of New York contains many interesting species of this genus.

Position and localities.—Independence shales near the base of the Iowa Devonian section at exposures numbers one and three near Brandon, Iowa[46], where they were collected by Merrill A. Stainbrook and the author. A tray of unidentified specimens collected by Calvin[47] in the late seventies at Independence in shales of the same age as at Brandon contains one imperfect plate which is unhesitatingly referred to this species.

FLEXIBILIA Zittel

An order of dicyclic crinoids with a flexible dome and with freedom of the radial series above the lower brachials; infrabasals three, unequal. Plates thick, often short; arms uniserial and non-pinnulate. Tegmen flexible, with the roofed ambulacra

46 Proc. Iowa Acad. Sci., vol. XXVI, pp. 485-491, 1919; also, Iowa Geol. Surv., vol. XXVII, pp. 387-399.

47 Bull. U. S. Geol. and Geog. Surv., vol. IV, No. 3, pp. 725-730; 1878.

exposed. Stem always round. The order is strictly Paleozoic extending from the Ordovician to the Pennsylvanian (Des Moines) of Europe and America. Recently Doctor Wanner of Bonn has described some remarkable representatives of this order from the Permian of the Island of Timor, Dutch East Indies. This greatly extends the time range as well as the geographical distribution of the order.

ICHTHYOCRINIDAE Wachsmuth and Springer

Infrabasals horizontal, not appearing exteriorly and taking no part in the calyx wall (except in *Clidochirus*). Crown elongate or rotund. Rays widening upward to accommodate the expansion of the calyx. Three of the ten genera of this family occur in the Iowa Devonian.

CLIDOCHIRUS IOWENSIS n. s.

Plate XLII, figs. 19-34; plate XLIII, figs. 10-44.

Perfectly preserved plates and united IBB belonging, it is thought, to this genus, occur abundantly at certain horizons in the marly shales of the Lime Creek beds. The more easily identified parts are radials, primibrachs, and infrabasals. IBB three, two of them five-sided, the other four-sided; outline pentagonal, extending well beyond the column, plates turned upward distally and forming a part of the cup; sutures distinct. Column facet flat, surrounded by a definite rim; lumen small, quinquelobate, its angles radial in position; viewed from within the axial canal is seen to project upward above the calyx floor, its rim forming a roughly trilobate funnel—the lobes over the five-sided IBB being wider than the single lobe over the three-sided plate; between the lobes of the funnel and the floor of the calyx are several supporting ridges, two or three on the larger plates and but one (or two) on the small plate; these ridges extend distally reaching quite to the edge of the plate in some cases. Within, the funnel is channeled, its grooves being limited by their septa which continue downward to form the re-entrant angles in the quinquelobate lumen; the channels pass directly downward and without torsion. The funnel, just described, was the seat of the chambered organ, the chief nerve center of the crinoid and the downwardly extended grooves are the paths of the five axial nerve cords. The distal faces of the IBB plates have deep pits or fossae, and sharp ridges limit those portions of the edge of the infrabasal circlet which opposed the proximal face of each of the five basals. BB large, curved, not in contact with the stem, polygonal; one or two, which are larger and heptagonal, are thought to be examples of the modified posterior basal which supports the anal series. RR pentagonal, wider than long, thicker than BB, distal face showing articulating ridge and groove. One or two thick, irregular, many sided plates are set aside as anal pieces. IBr_1 thick, three to four times as wide as long; IBr_2 pentagonal, axillary; besides these occur pieces which are evidently IIBr and higher orders.

Surface of plates of lower cup smooth; the RR are finely granular and succeeding plates are more so.

Remarks.—The radials and brachials of this species might well be compared with those of *Lecanocrinus.* Indeed in some former notes the writer referred them with some doubt to that genus[48]. Since then close search has resulted in finding several specimens of the united IBB which show that they are large and protuberant as in most of the species of *Clidochirus* and are not concealed by the stem as in all known Devonian species of the former genus. Similarly they may be compared with those of *Ichthyocrinus* but again the large IBB are markedly different from the hidden and often resorbed IBB of that genus.

The fine development of the funnel in this species illustrates well the features of that interesting anatomical structure. In the description given above the writer has drawn freely on Doctor Springer's excellent elucidation of it in his recent work on the flexible crinoids.

This species of *Clidochirus* extends the range of the genus into the Upper Devonian although a doubtful successor is known from the Mississippian of Kentucky.

Position and Localities.—In the upper part of the fossiliferous marly shale of the Lime Creek beds; found at several local-

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48 Bull. G. S. A., vol. 31, p. 212, 1920.

ities on the high hills just west of Rockford and at Bird Hill and vicinity.

CLIDOCHIRUS (?) MAXIMUS n. s.
Plate XLII, figs. 35-37.

A very large, thick axillary IBr is tentatively referred to this genus. The surface of the plate is strongly arched in the direction of its width and is gently curved longitudinally. The proximal and distal faces show well the articulating ridges and grooves. Lateral faces smooth, that on right covering but about two-thirds of the extremity, the other third is rounded, distal in position, and evidently not in contact, suggesting that the plate probably belongs in the left posterior ray, in the lower part of which ray contact is lacking in this genus. Surface marked by numerous small and evenly distributed granules.

Length of plate at middle 7.7 millimeters, greatest width 16.0 millimeters, greatest thickness 7.5 millimeters.

Remarks.—This solitary plate from the Independence shale is the only bit of crinoid found in that limited formation except the plates of *Arthracantha mamelonifera* described earlier in this paper and some stem segments. The unusual proportions of the plate suggest the specific name *maximus* which is offered for convenience in faunal lists and references.

Position and localities.—Independence shale, at exposure number two[49] near Brandon, Iowa. Collected by the author.

EURYOCRINUS BARRISI Springer.
Plate XLIV, fig. 8; plate XLV, fig. 12.

1920. *Euryocrinus barrisi* Springer. Crinoidea Flexibilia, p. 316. Plate 40, figs. 1-3.

> "A large species, with elongate crown; broadly truncate and excavate at the base; height, 50 mm.; width at IIIBr, 24 mm.; base, 10 mm. Calyx with nearly straight sides, spreading from outside of basal rim to top of IAx, 1 to 1.5. Cross-section at first bifurcation sharply pentagonal. Arms closely abutting to third axillary, with a more or less angular median elevation,

49Proc. Iowa Acad. Sci., vol. 26, p. 487.

and raised winged buttresses at sides of brachials; they are broad below, tapering rapidly with rather short divisions to four bifurcations, beyond which they are more rounded and divergent. Sutures arcuate. Base broadly and shallowly concave. iBr few, spaces narrow with the rays meeting above them. Surface smooth, except for the angularities and marginal elevation of the brachials.

IBB rather large for this family, but entirely within BB, and not filling the column facet. BB large, forming the greater part of the basal rim, and visible in side view as good-sized elongate triangles; post. B narrow and very elongate, nearly as high as RR, followed by one anal plate with a few others succeeding in one principal series and some smaller plates at the side. IBr 1, moderately large, angular, with one or two smaller ones following in large specimens; arched over by the winglike projection of the axillaries; iIIBr sometimes present. RR large, wider than succeeding IBr, their lower angles curving into the basal cavity. IBr 3 short and wide, increasing in width to the axillaries. IIBr 3. IIIBr 4 or 5 inner, and 8 or 10 outer; plates of these series as well as the upper two IBr very short and wide, meeting and interlocking laterally by angular margins, with a prominent node or ridge at the angles. All higher brachials very short and wide. Column large, with excavate facet less than diameter of basal rim; tapering slowly from the calyx and gradually changing from short to longer and alternating columnals."—After Springer.

Remarks.—The original illustration of this fine species from Buffalo is here reproduced with the permission of Doctor Springer. A much broken and incomplete calyx found in one of the ravines below Davenport is referred with some doubt to this species. The plates are smooth but some of them show the angularities characteristic of *E. barrisi.* It was collected by Rev. U. A. Hauber and kindly given the author for study. In the Springer collection are two from Partridge Point, near Alpena, Michigan, collected by Barris, in whose honor the species was named.

Position and locality.—Cedar Valley beds at Buffalo, Iowa. Also in the Devonian, Traverse group, Alpena, Michigan.

DACTYLOCRINUS Quenstedt.

Infrabasals wholly within the basals and concealed by the column. Rays above the radials separated by a single interbrachial but in contact for some distance above this plate. Posterior radials separated by a single anal plate followed by one (or two) small plates in series. No radianal. Arms heterotomous; IBr two, IIBr three, IIIBr three (or more).

DACTYLOCRINUS STELLATIMBASALIS n. s.

Plate XLIV, figs. 1-5.

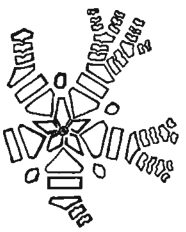

FIG. 73.—Analysis of the calyx of *Dactylocrinus stellatimbasalis*. The left anterior ray is incomplete beyond the first primibrach.

Description based on a single specimen with a nearly perfect calyx—the holotype.

Body small, sides broadly rounded, right and left posterior and right anterior rays partly preserved; a number of the plates of the other two arms are jumbled together over the tegminal region. Calyx slightly deformed by compression and as a result the right and left diameter at the top of the RR is 7.7 millimeters, while the antero-posterior diameter at the same level is 8.5 millimeters; height of calyx to top of RR about 3 millimeters, to top of $IIBr_3$ 7.5 millimeters. IBB unknown.

BB five, proximal part of each bent abruptly inward and upward to form the basal concavity; proximal edges concealed; apparently pentagonal except the posterior basal which is hexagonal. The distal edges of each basal beginning with the posterior plate and proceeding to the right would make, if produced, angles of about 35, 61, 44, 55, and 50 degrees respectively. Viewed basally the five plates strikingly resemble a five-pointed star.

RR large, wider than high, hexagonal or heptagonal, each plate pointed proximally and resting in the broad angle between two points of the basal star. RR in contact all around except on the posterior side where they are separated by the anal plate.

IBr two, the first of which is elongated quadrangular being about three times as wide as high; the second or axillary is pentangular. IIBr three; IIIBr three in place—plates beyond these not in position. The plates of each ray are in contact laterally with those of the adjacent rays except for a single small hexagonal or heptagonal iBr which is situated between the IBr and extends down for a short distance between the distal corners of the RR. Between the left anterior and left posterior rays the iBr is missing, evidently having been crowded out when the specimen was compressed as mentioned above. In the posterior iBr area a heptagonal anal plate rests on the truncated apex of the basal separating the RR and the quadrangular IBr of the posterior rays. Above the anal plate is a small vacant space from which, judging from the surrounding facets, apparently one or two small plates have been lost; the adjacent IBr and IAx of the left posterior ray are slightly skewed out of their natural position. This accident, it seems, loosened the small plate (or plates) and permitted them to drop out. The missing iBr, mentioned above, was at the opposite side of the displaced IAx of the left posterior ray.

Column small, round, 1.8 millimeters in diameter; a few thin columnals preserved in the depressed base; central perforation minute, obscurely five-sided; depth of basal depression, as exposed along the stem, 1.2 millimeters.

Surface of the BB and RR smooth; IBr and iBr granular, the granulations increasing in prominence on the plates distal to these. Sutures distinct, flush with the surface, those between the brachials characteristically arcuate as in many of the Flexibilia.

Remarks.—This delicate and rare species is to be compared with *D. concavus* (Rowley) of the Craghead Creek shale of the Devonian of Missouri which is larger, more rotund, and has a broader base than ours; moreover the plates of the Missouri species are all smooth. Two figures of Rowley's type are included in the plate for comparison—for these the writer has to thank Doctor Springer. It is a matter of keen regret to the author that the Iowa species did not get into the hands of the author of the Crinoidea Flexibilia in time to appear in that great work. Only seven species, including *D. stellatimbasalis*, of this genus are known. Three of these occur in the European Devonian, as follows: one from the Upper Devonian of Russia, one from the Upper Devonian of Belgium, and one from the Middle Devonian of the Eifel, Germany. The American species are from the central part of the United States, namely in Missouri, in Iowa, and at Alpena, Michigan, in Devonian beds of approximately the same age; the fourth is a doubtful species and comes from the Mississippian (Waverly) beds near Richfield, Ohio.

Position and locality.—In the marly shales of the Lime Creek beds of Cerro Gordo county in the southeast quarter of section 13, township 95 north, range 19 west, near the top of the beds. It was collected by Mr. C. H. Belanski.

TAXOCRINIDAE Wachsmuth emend. Springer

Flexible crinoids in which the posterior interradius is always differentiated and occupied by anal plates in a tubelike series and not incorporated in the calyx. Rays above the radials partly or wholly separated all around. Crown in most cases elongate. They extend from the Ordovician to the Mississippian; three genera and eleven species are known from the American Devonian, eight additional Devonian species are found in Europe. Two species have been reported from the Iowa Devonian, the type of neither of which has been seen.

EUTAXOCRINUS GRACILIS (Meek and Worthen).
Plate XLIV, figs. 17, 18.

1865. *Taxocrinus gracilis* M. and W. Proc. Acad. Nat. Sci. Phila., vol. XVII, pp. 142, 143.

1866. *Rhodocrinus* (*Taxocrinus*) *gracilis* Shumard. Trans. Acad. Sci. St. Louis, vol. II, p. 397.

1868. *Taxocrinus gracilis* M. and W. Geol. Surv. Ill., vol. III, p. 421, text fig., and Pl. 13, fig. 3.

1879. *Taxocrinus gracilis* W. and Sp. Rev. Paleocr., I., p. 48.

1920. *Eutaxocrinus gracilis* Springer. Crinoidea Flexibilia, p. 367, Pl. XLIX, figs. 8a, 8b.

> "Body small, expanding moderately from the base. Basal pieces small, and looking like the last joint of the column divided into three pieces; subradial pieces so small and narrow as to allow the lower middle ex-

tremity of the first radials to come nearly, or in some instances, quite down upon the basal pieces; four of them triangular and more or less wedge-shaped so as to project up between the first radials as much as half the length of the latter; the fifth one larger than the others, but slightly tapering, and truncated above by the anal? piece, so as to present a quadrangular or subpentagonal outline. First radial pieces considerably larger than the subradial, of nearly equal length and breadth, or a little wider than long, hexagonal in form, the inferior sloping, and upper horizontal sides much larger than the others. Second radials, in four of the rays, shorter than the first, wider than long, and generally hexagonal; in the fifth ray of the specimen under investigation, the second piece has its right margin enormously, and perhaps abnormally, developed, and extended obliquely upwards, so as to fill the whole interradial space above the comparatively minute interradial piece, quite as far as the second bifurcation of the rays, with one solid plate. In the ray containing this singularly developed second piece, there are two other primary radial pieces succeeding it, of near the natural size and form, upon the last (fourth) one of which the first bifurcation takes place; after this each of the divisions bifurcates again on the fourth piece, and the two inner subdivisions again on the fourth piece, while the two outer ones send off subdivisions, one on the sixth, and one on the seventh piece. In the ray immediately to the right of that just described, and apparently the anterior one, no division takes place until upon the eighth piece, all the pieces between the second and eighth being transversely oblong or about twice as wide as long, and gradually diminishing in size. In the other three rays, the first division takes place on the third piece, and the second and third divisions also on the third piece, the arms rather rapidly diminishing in size with each bifurcation.

Interradial pieces very small, rather longer than wide, somewhat wedge-shaped above, and resting between the short superior lateral sloping sides of the first radials, and supporting on each superior sloping side a short truncated margin of the contiguous second radials, which generally meet over the little interradial, so as to isolate it from the free space above, though not always. Anal piece a little larger than the interradials, hexagonal in form, and resting with one short side upon a truncated upper side of the largest subradial; while it connects on the right with a first and second primary radial, and on the left with a second and third primary radial, and one first secondary radial.

Surface of body apparently smooth, but showing granules on some of the divisions of arms. Patelliform accessory pieces not developed between the primary radial pieces, but quite distinct between some of the secondary. Column, as in other species of the group, round and tapering downwards from the base, near which it is composed of very thin pieces."—After Meek and Worthen, 1865.

This species was described from an abnormal specimen. However, Springer gives it as his opinion that "it is probably a good species representing the genus in the western Hamilton" just as for example *E. whiteavesi* represents it in the eastern Hamilton. The writer has collected imperfect fragments of what is apparently a Taxocrinid in the Buffalo region but no material of specific value and that found may belong to the next species.

The type specimen is in the University of Illinois and the matter of its geological horizon and locality is somewhat confused. In the original description Meek and Worthen list it from the "Hamilton at New Buffalo, Iowa", and compare it with *Taxocrinus interscapularis* Hall, "from the same locality". In Shumard's catalog, listed above, New Buffalo is likewise given as the locality. In the republication of the species in volume III, Illinois Geological Survey, the authors again compare it with *T. interscapularis* "from the same locality" but cite locality and position "Same as the last" which is *Microcyclus discus* from the Hamilton of Jackson county, Illinois, where occurs an entirely different Devonian basin and quite remote from the area about (New) Buffalo. Wachsmuth and Springer in Revision Paleocrinoidea list it from Devonian of Jackson county and again in the Crinoidea Flexibilia Springer gives the Jackson county reference. Barris[50] includes

[50]Proc. Davenport Acad. Sci., vol. 7, p. 27, 1899.

the species in his list of the rarer fossils of the *Spirifer pennatus* beds of the vicinity of Davenport.

Dr. T. E. Savage of the University of Illinois, to whom the author submitted the discrepancy, says "the label on each of these types (*T. interscapularis* and *E. gracilis*) states New Buffalo, Iowa, as the locality from which they came. I assume the Illinois Report was in error in stating locality in such a way as to indicate Jackson Co., Illinois".[51] In view of these facts the author is convinced that the original specimen was collected in the Devonian beds near Buffalo.

In Barris' list just mentioned is included also *Taxocrinus nuntius,* now known as *Synaptocrinus nuntius* (Crin. Flex., p. 302). To the writer this is the only known reference to a western occurrence of this species. Barris' identification is probably incorrect and may be regarded as an effort on his part to identify the imperfect Taxocrinid material which he found at and near Davenport.

TAXOCRINUS INTERSCAPULARIS Hall.
Plate XLIV, fig. 10.

1858. *Taxocrinus interscapularis* Hall. Geol. Surv. Iowa, I, pt. 2, p. 482, pl. 1, fig. 3.

1879. *Taxocrinus interscapularis* W. and Sp. Rev. Paleocrin., I, p. 48.

1920. *Taxocrinus interscapularis* Springer. Crinoidea Flexibilia, p. 385, pl. LII, fig. 6.

Not *Taxocrinus interscapularis* Cleland. Wis. Geol. Surv. Bull. 21, p. 42, pl. 3, figs. 11, 12, 1911.

> "This species is only known by a single specimen, and that is in such an imperfect condition that no satisfactory detailed description can be made from it. One side is imbedded in a hard matrix, and the exposed part is much injured by weathering and accident; the base is broken off, and the basal plates described by Hall are part of the radials, according to the interpretation by my artist; it apparently has 3 IBr instead of 2, as would follow from the original description. There are two peculiar things about the

51Personal communication, March, 1923.

specimen: (1) the high location of the iBr, supported by the IBr_2, instead of R as in other cases; (2) that the inner division of the IIIBr is longer than the outer. There is also a tendency in the brachials to coalesce for two or three ranges above the axillaries, which is not seen elsewhere in this genus. The species is apparently well-marked by these characters, but its relations remain obscure; and it may even not belong to this genus, as the anal side is unknown."—After Springer, 1920.

Position and locality.—Lower part of Cedar Valley limestone in vicinity of Buffalo, Iowa. The type is in the University of Illinois.

INADUNATA Wachsmuth and Springer

An order of crinoids which are monocyclic with a few families dicyclic. Plates of the cup firmly united. Calyx includes the basals (and infrabasals when present), radials, and anal plates. Brachials never form a part of the cup. Arms may be pinnulate or non-pinnulate, biserial or uniserial. Range, Ordovician to Triassic.

SYNBATHOCRINIDAE Wachsmuth and Springer

Small monocyclic crinoids with five basals in the primitive forms but only three unequal basals in the later genera; radials five. Long anal tube. Arms five, simple; column round.

SYNBATHOCRINUS MATUTINUS Hall.
Plate XLIV, fig. 9.

1858. *Synbathocrinus matutinus* Hall. Geol. Surv. Iowa, vol I, pt. 2, p. 483, pl. 1, fig. 2.

1885. *Symbathocrinus matutinus* W. and Sp. Rev. Paleocr., pt. III, p. 169.

1923. *Synbathocrinus matutinus* Springer. Smith. Misc. Coll., vol. 76, no. 3, p. 29.

"Basal plates undivided, forming a slightly projecting disc in the specimen: first radial plates wider than long; second radials longer than wide, obtusely angular along the centre; brachial plates quadrangular, and subangular longitudinally along the centre: column round, composed near the base of alternating larger and smaller rings.

The only specimen seen is a fragment, imperfect at the upper extremity, with the surface much broken, and particularly the basal and first radial plates, while the surface of the arm-plates has been exfoliated. The structure, therefore, is not very satisfactorily determined, though the peculiar form of the crinoid and the succession and arrangement of the plates are sufficient to distinguish it from any other established genus of crinoids."—After Hall, 1858.

No additional specimens of this rather obscure species have been collected so far as known.

Position and locality.—Cedar Valley shaly limestone in "*Stropheodonta demissa* bed," near Buffalo, Iowa, and in Michigan.

CREMACRINIDAE Ulrich

Crinoids with monocyclic, asymmetric calyces due to the bending of the stem so that the calyx nodded or turned permanently downward; as a result the plates are shifted from their conventional positions to new ones. BB on posterior side of calyx and connecting with the RR of the anterior side by a flexible articulation. Arms three or four.

Deltacrinus barrisi (Worthen).
Plate XLIV, figs. 20, 21.

1875. *Calceocrinus barrisi* Worthen. Geol. Surv. Ill., vol. VI, p. 510, text fig.

1885. *Calceocrinus barrisi* W. and Sp. Rev. Paleocr., III, pp. 276, 281.

1893. *Calceocrinus barrisi* Bather. Crin. of Gotland, pt. 1, p. 66 (in a list).

"Body above the medium size and composed of thick massive plates. Lower dorsal plate triangular and about three times as wide as high. Upper dorsal plate less than half the size of the lower, and triangular in outline. Dorso-lateral pieces presenting an irregular pentagonal outline, with abruptly rounding lateral sides, and projecting upper angles. Arms and column unknown.

This species may be readily distinguished from any other known to us by its thick massive plates and robust appearance.''—After Worthen, 1875.

Remarks.—The type specimen has not been seen but in the Davenport Academy collection there is a part of a specimen composed of three plates, showing stem facet and an articulating face. Its plates are delicately granular. It is assumed to belong to this species.

Position and locality.—In the Phragmoceras zone[52] of the Upper Davenport beds[53], Davenport, Iowa. The Davenport Academy specimen comes from Cook's Quarry, Davenport, and was collected by Professor W. H. Pratt. Barris lists the species as coming also from the Devonian of the Rock Island and Moline area in Illinois[54].

CYATHOCRINIDAE Roemer

Dicyclic crinoids with a heavy tegmen; anus passing through the side of the cup as in *Gasterocoma,* through the tegmen as in *Carabocrinus,* or at the end of a tube as in *Cyathocrinus.* Arms non-pinnulate. Radial facets semicircular and narrower than the width of the radial. Infrabasals usually five. Stem in most cases round.

CYATHOCRINUS ROCKFORDENSIS n. s.
Plate XLIV, figs. 11-16.

Radials bearing the horse-shoe shaped facets characteristic of this genus are fairly common at certain zones in the marly shales of the Lime Creek beds. The plates are sub-pentagonal, smooth, quite thick, and their sides are nearly parallel; the facet is directed upward and outward and is bordered by a sharply raised rim; the notch at its inner edge for reception of the ambulacral groove is rounded and fairly deep; the two proximal side-faces meet in a sharp point. An average radial is about 7.5 millimeters wide and close to 6.8 millimeters in

52Proc. Davenport Acad. Sci., vol. VII, pp. 17, 18 (Barris); 1899.
53Geol. Surv. Iowa, vol. IX, p. 451, 1899 (Norton).
54Proc. Davenport Acad. Sci., vol. II, p. 267, 1878.

length. Several plates which may be basals, and others which may be brachials, occur with these radials but since the loose plates of *Clidochirus iowensis* are also found at practically the same horizon it is not practical to assign them with certainty to either of the two genera since they are not so characteristically marked as are the radials of *Cyathocrinus* and the radials and primibrachs of *Clidochirus*.

Position and localities.—In the marly zone of the Lime Creek shales near its top at Bird Hill and vicinity and at the outcrops west of the Rockford Brick and Tile plant, Rockford.

POTERIOCRINIDAE Roemer

Dicyclic crinoids with tegmen of undifferentiated plates often swollen into a ventral sac; arms pinnulate, usually dichotomous. Infrabasals five (or three), frequently coalesced. Devonian to Permian.

POTERIOCRINUS BUFFALOENSIS Worthen.

Plate XLIV, fig. 19.

1890. *Poteriocrinus buffaloënsis* Worthen. Geol. Surv. Ill., vol. VIII, p. 89, pl. 12, fig. 1.

> "Calyx small, obconic below the summit of the radial plates, or about once and a half as wide as high. Basals small, pointed above, forming a low pentagonal cup.
>
> Radials two on each of the two rays visible, the first pentagonal wider than high; the second quadrangular and about twice as wide as high.
>
> Brachials pentagonal, wider than high, pointed above, and supporting on their upper sloping sides the first arm plates.
>
> Arms two to each of the rays visible, composed of rather stout joints that are longer than wide, and project slightly at their upper margins where they support stout pinnules.
>
> Anal series unknown.
>
> Column rather stout where it joins the body, composed of slightly projecting plates that diminish gradually in size below."—After Worthen, 1890.

The only specimen known to the author is in the Worthen collection at the University of Illinois.

Position and locality.—Cedar Valley limestone, near Buffalo, Iowa.

DECADOCRINUS VINTONENSIS n. s.
Plate XLV, fig. 1.

A single flattened specimen firmly attached by one side to the matrix is made the basis of this species. The arms are fairly well preserved and a part of the proximal portion of the stem remains.

Calyx small, base apparently flat, sides expanding gradually but the cup is not spacious; plates smooth. Arms long, dichotomous, the two parts strictly equal; joints of arms thicken distally especially those joints which give rise to the pinnules—this feature gives the arms a knotted appearance. Pinnules fairly strong and all turn abruptly upward. Six arm divisions, or the equivalent of three arms, are on the exposed surface. The right posterior arm shows both divisions; between it and the left posterior couplet a series of plates rises up and tapers to a point five millimeters above the dichotom. These plates are interpreted as the base of the ventral sac on the posterior side.

Stem round, tapering distally, about fourteen columnals in five millimeters which is the length of the part preserved; height of calyx to the arm bifurcation, 7.5 millimeters, length of entire crown, 42 millimeters.

Remarks.—This specimen now in the Calvin collection was collected many years ago at Vinton by Mr. E. P. Whipple. Calvin submitted it to Dr. Frank Springer who labelled it "*Decadocrinus,* undescribed species, F. S." This generic determination has been followed in this paper.

Position and locality.—Devonian, exact horizon unknown, near Vinton, Iowa.

ECHINOIDEA Bronn

The Sea Urchins

This class of echinoderms has had a long history and their remains are known from Ordovician to Recent times. Their Paleozoic history previous to the Mississippian is quite meager there being according to Jackson (Phylogeny of the Echini, p. 236; 1912) but three Ordovician species, all from Russia; four Silurian species, three from England and one from the Niagara group in New York; and from the Devonian five genera and ten species. Of the latter only one species is described from America, seven come from Germany, and two from England. In the same year Olsson[55] described a new genus and species, *Lepidechinoides ithacensis,* from the Upper Devonian at Ithaca, New York. This made only two genera represented by one species each in the American Devonian up to the time the writer reported three additional genera from Iowa.[56]

The Iowa material is composed largely of loose plates, spines, and parts of the lantern, all very well preserved, but its dissociated condition leaves us somewhat in ignorance as to the characters of the complete tests. A part of an interambulacrum of *Nortonechinus,* found at Rockford, does aid materially in the interpretation of that genus. However, the mode of imbrication and the position and relation of the spines had been determined before the fragment of the test was obtained. Of *Xenocidaris,* specimens only of the slender-shafted spines, a hemipyramid, and one doubtful plate have been collected; due to the general similarity of the spines of the two genera both are placed in the same family in this paper. *Devonocidaris* is plentifully represented by a rather full complement of all the parts, belonging, however, to dismembered and fragile tests. The characters of its plates, as pointed out later, consign it, in the writer's opinion, to a different family. All three genera are placed in the order Perischoëchinoida, a brief diagnosis of which, as well as of the families involved, is given below. In these diagnoses the work of Jackson is closely followed.

PERISCHOËCHINOIDA M'Coy

Echinoids with regular tests in which the periproct is within the oculo-genital ring; usually spheroidal in shape. Ambulacral areas with two to twenty columns of plates, all simple and

55 Amer. Jour. Sci., 4th ser., vol. 33, pp. 442-446, 1 fig.; 1912.
56 Bull. Geol. Soc. Amer., vol. 31, p. 212; 1920.

bearing one pore-pair each. Interambulacra with three to fourteen columns of plates. With few exceptions the plates of the adambulacral columns are pentagonal, and those of the median columns hexagonal. Plates thick or thin, and bearing primary perforate tubercles and spines with secondaries, or secondaries only. Plates of the test may or may not be imbricate. Interambulacrals, when imbricate, do so aborally and from the center laterally and over the adjacent ambulacral plates. Genitals have three to many genital pores. The lantern is inclined and composed of forty pieces. Teeth grooved, pyramids wide-angled, foramen magnum moderately deep, epiphyses narrow, capping the half-pyramids; brace and compass as in modern echinoids.

ARCHEOCIDARIDAE M'Coy

Test spheroidal or depressed; ambulacra narrow, with two columns of plates in each area. Pore-pairs uniserial or slightly biserial. Four to eight columns of plates in each interambulacrum (*Nortonechinus* has at least eleven, possibly twelve or fourteen, rows) more or less imbricating aborally. Interambulacral plates bear a large central perforate primary tubercle and scrobicule; large primary spine, also secondary tubercles and spines. Oculars and genitals unknown or very doubtful.

NORTONECHINUS Thomas

1920. *Nortonechinus* Thomas. Bull. Geol. Soc. Amer., vol. 31, p. 212; also in Science, n. s., vol. lii, p. 89.

Genus based on a part of a broken test, a large number of dissociated plates and spines, and parts of the lantern. The fragment of the test is a portion of an interambulacral area with a large number of rows of plates which are strongly imbricate aborally.

Ambulacral plates small and thin bearing one pore-pair each; on the inner surface is an articulating hooklike process which aids in the imbrication.

Interambulacral plates fairly thick, rounded pentagonal in outline but the elevated portion within the sutures is polygonal or rounded polygonal, the number of sides being six, rarely four, or five; plates imbricate, the outer bevel developed adorally into a broad flange which is overlapped by the inner bevel of the next adoral plates. Each plate bears a low, perforate, median tubercle, has a fairly wide scrobicular area and a low basal terrace.

Primary spines greatly expanded distally until on the crowded parts of the test they are rendered polygonal by mutual contact; the base concave, milled ring absent, fine vertical striations, apical face pustulose or slightly spinulose. The development of secondary spines doubtful; a few miliaries.

Parts of jaw-apparatus large and very similar to those of modern species.

The striking features of this genus are the large number of columns in the interambulacra, the greatly modified plates to meet the demands of the excessive imbrication, and the remarkable distal expansion of the primary spines.

This genus seems to be most nearly allied to *Archeocidaris,* a genus not yet reported below the Mississippian, but differs from it in having more columns of interambulacral plates, in having variably polygonal rather than regularly hexagonal (adradials pentagonal) plates, in the far greater development of the imbrication, in having mutually compressed spines, and in the absence of a milled ring on the spine. In fact the large number of columns in each interambulacrum makes reference to the family Archeocidaridae untenable without a redefinition of the family.

The strong imbrication recalls *Eocidaris* of the Devonian of Germany but the presence of a basal terrace and the character of the spines in *Nortonechinus* strongly set it off from that, unfortunately, imperfectly known genus.

A few of the more slender spines of *Nortonechinus,* presumably from the younger parts of the test, terminate in circular or spinulose expansions; these somewhat resemble the club-shaped spines of *Xenocidaris,* elsewhere described in this paper, but this resemblance is more likely a case of parallel adaptation than of close relationship.

The occurrence of expanded appendages is rare in early echinoids. The feature reached remarkable development and diversity in the cidarid echini, especially during the Mesozoic. Bather in his "Triassic Echinoderms of Bakony" has treated very ably the Bakony genera which show distally enlarged spines. In the Paleozoic such development was heretofore unknown barring the moderate distal expansions of *Xenocidaris* mentioned above. In the modern seas, however, remarkable modifications of the spines occur reaching an extreme in the tessellated spines of *Colobocentrotus atratus* Brandt,[57] which are distally expanded and rendered polygonal by compression very much as were the spines of *Nortonechinus*. (See text figure 79.)

Spines and plates of this remarkable echinoid were collected some years ago by Dr. William Harmon Norton, Professor of Geology, Cornell College, Mount Vernon, Iowa. Doctor Norton very kindly loaned the material for study and the author takes much pleasure in naming the genus in his honor. Since then a considerable quantity of the remains has been added by the writer and others.

Genotype, *Nortonechinus welleri*.

NORTONECHINUS WELLERI n. s.

Plates XLVII, figs. 1-7; XLVIII, 1-49; XLIX 1-6 and 8-23.

This interesting echinoid is represented by a part of a test, here made the type, by isolated plates and spines, and by parts of the lantern. The test fragment is a part of an interambulacral area, presumably from near the ambitus. The specimen is approximately five by six centimeters in greatest dimensions and together with the mass of adhering plates, spines and so forth on the interior surface is about one centimeter in thickness.

On the outer surface are fifty-five contiguous plates arranged in natural order except for some distortion and the slipping of a few plates out of line. The inner surface is covered with a jumble of interambulacral and a few ambulacral plates, spines, and parts of the lantern. The bulk of the speci-

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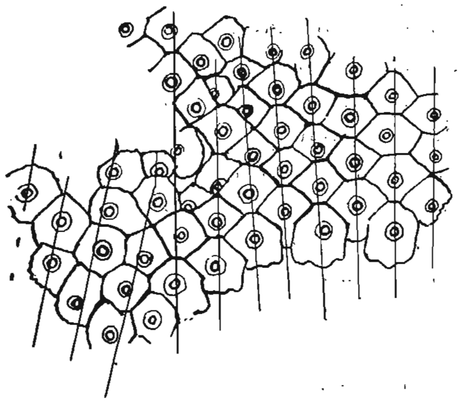
57 "A Treatise of Zoology," edited by E. Ray Lankester, Part III, The Echinoderma, p. 314, text figure xxxiv, London, 1900.

men is evidently a conglomerate of this character held together by the soft clayey matrix.



Nortonechinus welleri Thomas
FIG. 74.—A tracing of the outlines of the plates in the type specimen to show the meridional as well as the diagonal arrangement of the rows. The alignment is somewhat imperfect due to partial distortion of the specimen especially in the region of the fourth and fifth rows from the left. Moreover the plates of this area are partly concealed by adhering spines. After figure 7, plate XLVII.

The plates of the natural surface form parts of eleven or possibly twelve meridional rows and illustrate well the strong aboral imbrication. On the upper left hand corner of the specimen (as oriented in the illustrations) is a cluster of eight or ten primary spines held in place by the clay, some of them in positions approximating their original relation to the test; elsewhere over the surface several fine, delicate miliary spines lie attached more or less firmly to the plates. Unfortunately only a few plates remain in the right and in the left rows but those remaining do not appear to be adradials, from which it may be concluded that the ambulacrum had at least thirteen or possibly fourteen rows of plates. The imbrication is of such a character that diagonal rows in either direction are much more apparent than the meridional rows. Referring again to the inner surface it will be found that the confused mass is made up chiefly of interambulacral plates and primary spines; there are also a few miliaries, some ambulacrals standing on edge in a closely packed row, and in one corner is a brace 11.5 mm. in length.

Plates of the interambulacrum thick and strongly imbricate; an average free plate is rounded polygonal or roughly pentagonal in outline and is made up of three areas, the intrascrobicular, the extrascrobicular or intertubercular tract, and the marginal border. An examination of the inner surface of the plate reveals the fact that approximately one-half of it is bevelled obliquely. With this fact in mind the plate may be oriented according to Duncan's rule[58] that in a meridional series of interambulacral plates the adapical margins are bevelled on their inner surfaces; hence, the broad flange on the plates of this species is an adoral extension which is bevelled on its outer surface and grows thinner toward its margin.

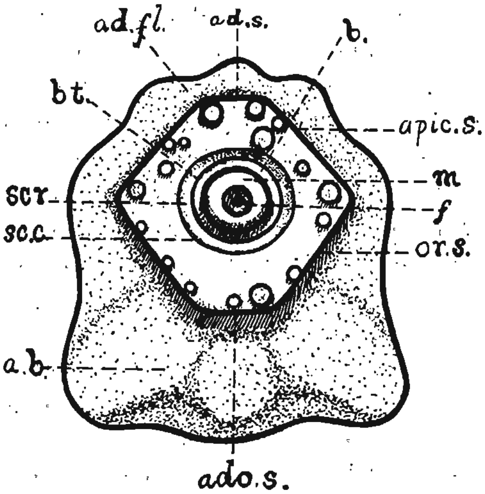


FIG. 75.—Diagram of an interambulacral plate of *Nortonechinus welleri* Thomas to illustrate the terminology used in the text. *sc. c.* scrobicular circle, *scr.* scrobicule, *b. t.* basal terrace, *b.* boss, *m.* mamelon, *f.* foraman, *ad. s.* adapical suture, *apic. s.* apicad-interradial suture, *or. s.* orad-interradial suture, *ado. s.* adoral suture, *a. b.* adoral bevel, *ad. fl.* adapical flange. The area between the scrobicular circle and the sutures is the intertubercular tract; the secondary spine bases on this area form a nearly perfect circle in some echinoids and are called the scrobicular ring. The space within the scrobicular circle is known as the intrascrobicular area. Drawn by *E. Drewelowe Van Ek.*

The intrascrobicular area bears a low-domed mamelon centrally perforated by a round foramen whose diameter is about one-third that of the mamelon. The neck of the mamelon is straight in most specimens and grades downward into the gently concave surface of the boss; in a few specimens the neck is slightly undercut in which cases a narrow flush platform is developed; basal terrace faint and but little elevated; the scrobicule is narrow, its width being about one-fourth of the radius of the intrascrobicular area, its floor is sunken but a trifle below the extrascrobicular surface; a well defined scrobicular circle marks the limiting boundary of the intrascrobicular area.

The extrascrobicular area, as here interpreted, is that part of the surface between the scrobicular circle and the sutures, which surface in our specimens is polygonal or subpolygonal in outline. The scrobicular ring is imperfectly developed on most plates and consists of a few low, irregularly spaced, rounded nonscrobiculate tubercles; the presence of a perforation is

58 Revision of the genera and great groups of the Echinoidea. Jour. Linn. Soc., Zool., xxiii, pp. 295-304; 1889.

doubtful; beyond and among these on the intertubercular tracts of some plates a few scattered granules are present. The total number of tubercles and granules is fifteen, or perhaps less, to twenty. The sutures vary in number and development according to the position of the plate in its column and of the column in the interambulacrum; the two most prominent and constant sutures are the two adoral oblique or "orad-interradial" sutures of Bather,[59] these two in a few specimens meet adorally at various angles but usually at about 90°, see figure 42, plate XLVIII; however, the angle thus formed is normally truncated by a transverse adoral suture; the adapical oblique or "apicad-interradial" sutures meet adapically in a very few instances, see third specimen, figure 36, plate XLVIII; in some specimens the last named sutures are truncated by a transverse, fairly well defined adapical suture, see fourth specimen, figure 36, plate XLVIII, thus making the elevated parts of a few plates hexagonal, but these are comparatively rare; the most common adapical condition of the sutures is one in which the apicad-interradial sutures meet in a curved line, the curved part supplanting the transverse adapical suture, see figure 40, plate XLVIII.

FIG. 76.—Meridional section of an interambulacral plate of *Nortonechinus welleri*, about x5. The left hand end of the drawing is adoral. The adoral transverse suture is more abrupt in most plates than in the figure. Drawn by O. T. Walter from specimen U. I. C. 3096, the right half of which was ground off perpendicular to the surface of the plate.

The marginal border extends outward on all sides from the bounding sutures, its greatest extent being adoral, while a narrow flange extends completely around the plate; the edges of the plate proper, at the suture lines, are nearly vertical, in a few cases even a little undercut along the orad-interradial and adoral sutures, while adapically the edge is concave and grades gently into the flange. The adoral margin of the flange is lobate and subparallel to the adoral suture when that is present; in many specimens the adoral portion flares laterally, in which cases its width is greater than any other transverse dimension of the plate; the bevelled surface of the adoral flange is variously grooved and excavated, into the hollows of which fitted

59 Bather, F. A., Triassic Echinoderms of Bakony: Resultate der Wissen. Erforsch. des Balatonsees; vol. I, part 1, p. 61; 1909, Budapest.

similarly shaped eminences found on the inner bevel of the overlapping plates; there is no regular pattern on the bevelled surfaces and yet in a general way the right and left thirds of the inner bevels are excavated more than their centers and the adoral margin of the outer bevel in many plates is set off as a thin border from the rest of the imbrication; see second specimen, figure 1, plate XLIX; the adapical part of the flange is thin and is often produced medially as in figure 40, plate XLVIII.

The measurements of four typical plates in millimeters are:

	a	*b*	*c*	*d*
Height, or meridional diameter (greatest)	7.7	7.9	7.5	7.6
Width, or greatest transverse diameter	7.2	7.4	7.5	7.2
Height within the sutures	4.7	5.0	4.4	5.1
Width within the sutures	5.2	5.6	5.4	5.5
Diameter of the scrobicular area	3.1	3.4	3.5	3.4
Diameter of the boss	2.4	2.5	2.5	2.8
Diameter of the mamelon	1.5	1.6	1.7	1.55
Diameter of the foramen	.7	.75	.6	.7
Greatest thickness	2.8	2.5	2.45	2.4

A study of a group of plates assembled at random shows that the amount of imbrication is large, that the irregularities and eminences on the outer bevels had their counterparts on the opposing inner bevels, that when the proper plates were in juxtaposition the narrow adapical imbricating margins fitted more or less well against or beneath the nearly vertical or slightly undercut adoral transverse sutures; moreover, assuming that the interambulacrum had three or more columns of plates, it is seen that each plate (except the adradials) lapped adapically upon the extended margins of three plates and was in turn lapped adorally by three other plates.[60]

The structure of the plates under a lens shows the open cribriform tissue or stereom characteristic of the skeletal parts of echinoderms.

Ambulacral plates imperfectly known. On the inner surface of the type specimen, see figure 2, plate XLVII, is a row of sixteen small plates more or less firmly cemented and standing partly on edge. Their position among the debris is such that they cannot be wholly uncovered or readily removed. The series lies in a sigmoid curve and the plates are apparently in

60 This paragraph was written before the type specimen, number 8044, was found.

serial order, judging from the perfect way in which they fit together. An end plate of the row is so inclined as to expose its inner surface. It has a pore-pair whose openings pass obliquely through the plate. The openings are close to one millimeter apart and are approximately in line with the transverse diameter of the plate, which dimension is 4.8 millimeters. Thickness of the plate is one-half millimeter. Toward one end the plate narrows perceptibly; from one side of the wider end and opposite the pore rises a thickened process which curves outward and away from the body of the plate in a sort of hook; this fits over a similar process on the next plate and so on throughout the series. Total thickness of plate including the process is two millimeters. These overlapping hooks apparently have to do with a well developed adoral imbrication.

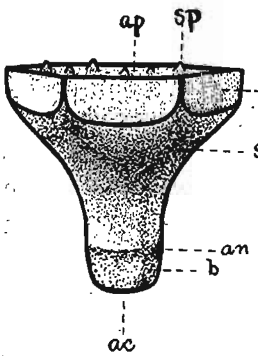


FIG. 77.—Diagram of a primary spine of *Nortonechinus welleri* Thomas to illustrate the terminology used in the text. *ap.* apex, *sp.* spinule, *f.* facet, *s.* shaft, *an.* annulus, *b.* base, *ac.* acetabulum. Fine microscopic striae pass longitudinally over the shaft and facets and converge to the center of the apex. Drawing by *E. Drewelowe Van Ek.*

The spines are short and expanded distally to such an extent that over the greater part of the test they seem to have been so crowded as to truncate each other by mutual compression. The condyle or acetabulum is round and broad, its depth about one-half its diameter, its margin sharply marked by a ring above which rises the base of the spine; the base has a gently convex surface and ends distally in a well defined annulus; the shaft contracts a small but perceptible amount above the annulus then its sides diverge gently at first thence abruptly to the broad terminal expansion; in a few specimens the shaft is subcylindrical for approximately half of its length above the annulus. Viewed apically most spines are polygonal in outline while only a few are rounded polygonal or circular; the number of sides most commonly observed is six, but specimens with five or even four sides are not rare; the sides are of slightly different lengths so that approximately perfect hexagons, pentagons, or squares are infrequent, especially the last. Another common outline is the subpolygonal in which some of the sides meet forming marginal angles while the remainder of the periphery is rounded. The apical surface is flat or nearly so and its greatest transverse dimension is often equal to or greater than the length of the spine; the surface is normally at right angles to the shaft but in a few specimens it is a little oblique; the sides of the polygonal apical portion when truncation is well developed form flat oblong facets whose surfaces are subparallel to the axis of the shaft and each is bounded by three straight and one curved line. (See text figure 77.)

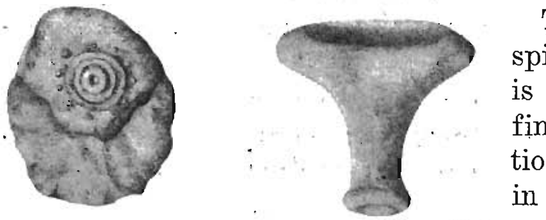


FIG. 78.—Interambulacral plate and primary spine of *Nortonechinus welleri* Thomas. Enlarged three diameters. Spine tilted to show the condyle or acetabulum. See figure 3, plate XLIX. Drawings by Miss Hilda Horn. In the drawing the scrobicular ring of tubercles occupies too small a part of the extrascrobicular area; compare the original.

The surface of each spine above the annulus is marked by exceedingly fine longitudinal striations, twenty-five to thirty in one millimeter; the striations continue up over the facets and the flat summit area where they converge from all sides toward the center. The summit is further ornamented by numerous short, blunt spinules or pustules which have a more or less definite radial arrangement; these spinules interrupt the courses of the striations and cause them to take winding paths quite in contrast with the precisely parallel courses pursued on the shaft.

A study of a number of spines whose apical expansion is round in outline brings out the facts that these spines are somewhat more slender, their summits tend to be shallowly concave instead of flat, their spinules are best developed marginally with a tendency to have a single prominent central spinule; in one specimen at hand the expanded apex is crateriform with a nearly smooth rim and in another the distal end is narrowly spatulate with a low longitudinal ridge along the center of one face of the spatula. A few spines, fully twice as long as those with the polygonal distal expansions, are nearly cylindrical for their entire length and terminate in three to seven sharp and fairly long subparallel points or prongs.

Measurements of four typical spines with six-sided apices are:

	a	*b*	*c*	*d*
Length (all figures in millimeters)	6.1	6.5	6.2	6.3
Greatest diagonal width across the apex	7.0	7.1	6.2	5.1
Greatest width of apex perpendicular to one of its sides	6.1	6.4	5.3	4.5
Vertical width of a facet	1.3	1.2	1.1	1.2
Diameter of the annulus	2.1	2.2	2.0	1.9
Height of the base	.7	.9	.9	.8
Diameter of acetabulum	1.4	1.6	1.5	1.4

Four of the long spines, Nos. 3051*a*, *b*, *c*, *d*, (Pl. XLIX, figs. 18-21) give a length and average diameter of shaft, respectively, as follows: 13.5, 2.5; 12.2, 2.6; 12.1, 2.5; 10.9, 1.9 mm. Specimen *b* is incomplete.

The lantern is represented by a few incomplete teeth, a part of a pyramid, and several finely preserved rotulas or braces. These have been found in close association with spines and plates.

Tooth gently curved longitudinally, inner surface flat with a shallow median groove which widens distally in most specimens at hand. The face of the tooth has a deep median groove flanked on each side by a rounded ridge; the slope from each ridge to the sharp-edged margins is broken by another but shallower groove which parallels the edge of the tooth; thus there are on the face three grooves, one median and two submarginal. The point is bevelled off from the face side and is strengthened by two sharp converging ridges which are continuations of those on the face. Under a lens fine lines are seen to run diagonally from the median groove to the edge of the tooth; these give each surface a herring-bone pattern. Total length of a tooth unknown. Specimen 3046a is 7.4 mm. long, 3.1 mm. wide, and 1.0 mm. thick; length of the bevelled point is about equal to the width of the tooth. Specimens of teeth are lighter in color than other parts and they break readily along the calcite cleavage.

Rotula strong, quadrangular in shape, wider than thick; both ends notched, the inner end deeply, the outer shallowly and broadly; a curved ridge borders the edge of the inner notch on the upper surface, beyond which the surface is flattened or depressed. The under surface bears a long V-shaped elevated area, the point of the V being near the inner end and separated from the notch by a shallow transverse groove. Dimensions in millimeters of three rotulas follow:

No.	length	width at midlength	thickness at midlength
3047	8.2	3.2	2.0
3048a	8.6	3.7	1.9
3048b	7.5	3.4	1.9

On the inner side of the type specimen is an example 11.5 mm. long; it is the longest rotula seen but its width and thickness are about average. Near it lies what seems to be a compass with only one end exposed. On the same surface and firmly attached in the matrix is a half pyramid, face view, showing deep pit for the retractor muscle; the specimen is close to 12 millimeters long.

The high specialization of this echinoid is extraordinary. The remarkable development of the imbrication must have afforded great flexibility to the test but it would seem that the flexibility was somewhat limited by the crowded spines. The cover of spine apices formed a more or less complete coat of mail over the test and its function could have been little other than that of protection. So completely did it envelop the test that the development of secondary spines is doubtful; the miliaries are very short—however, on parts of the test where the primary spines were not crowded they may have been longer. The long spines with the rounded or forked terminations differ from those of *Xenocidaris* in not being fluted, their shafts are stouter, and the marginal spinules are less regular.

A study of the primary spines throws little light on their orientation but by analogy it may be inferred that the greatest diagonal dimension of a six-sided apex is parallel to the equator of the test as is the case with hexagonal plates of the columns. The variations in the shapes and sizes of the spines, as pointed out by Bather[61] in his study of the radioles of *Anaulocidaris* and other genera, are not merely between spines of the same rank but there is a definite gradation of form according to the position of the spine on the test. The age of the spine is also a factor in variation while the degree of crowding undergone by the various spines determines quite largely the shape of the distal expansion as well as the sharpness of its marginal angles. In a communication some years ago Doctor Bather kindly suggested to the author that the spines of *Nortonechinus* are similar to the radioles of *Anaulocidaris* and that by analogy the roundly terminated spines of the former belong on the less crowded apical part of the test as in the latter. The very long prong-bearing spines are assumed to have been circumapical in position. However, their subsequent modification to short ambital spines demands progressive changes of which we do not have at present sufficient and convincing intergrading forms.

The nature of the type specimen permits some speculation on the size and shape of an entire individual. Transversely the specimen measures fully six centimeters; since apparently neither of the lateral columns is an adradial we must assume that there were at least two more columns in the interambulacrum, add to this the width of an ambulacrum and the width of the two areas would be at least eight centimeters. Multiplied by five this would give a circumference of forty centimeters or a diameter of close to 12.75cm.; add to this the length of the spines (6.3mm. x 2) and we would have a diameter of over fourteen centimeters or five and one-half inches for the living animal. Thus, if spherical in shape, it would approach the size of a large *Melonechinus*

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61 loc. cit., pp. 136, 137.

like those of the St. Louis limestone. The few long spines with the spiny terminations recall the flattened radioles about the basal rim of the hemispherical test of *Colobocentrotus* and like them may have been used as aids in locomotion. In such an event *Nortonechinus* may have been more or less hemispherical in shape; indeed it is difficult to understand how a form so encumbered by its type of primary spines could have moved about unless it had something of the shape of the Hawaiian *Colobocentrotus*. More complete tests are awaited with interest.

The shape of the teeth is very different from those of the Mississippian echinoids in that they are not keeled but are nearly flat. No known Mississippian echinoid seems to have inherited the features of *Nortonechinus*, which evidently reached its climax in the late Devonian and left no descendants.

The type specimen is in the University of Iowa collection; typical plates and spines have been sent to Doctor Jackson and are in the Museum of Comparative Zoology at Harvard; there is also a lot in the Walker Museum, University of Chicago, in the British Museum, London, and in the United States National Museum, Washington.

Occurrence.—Found in the marly shales of the Lime Creek beds in a zone ten to fifteen feet above the plastic blue shales. Locally they are abundant but at several stations at which this horizon is well exposed very few specimens have been found. The hillsides about the Rockford Brick and Tile Plant have proved good collecting places; Juniper Hill or "Nortonechinus Hill" about a mile to the northwest of the Tile Plant has yielded hundreds of spines and plates from small patches a yard or two in width. Dr. Norton's original collection of about twenty plates and some thirty primary spines was collected "on a small spot at Hackberry Grove."

The specific name is given in honor of Dr. Stuart Weller of the University of Chicago, under whose direction this study was initiated.

NORTONECHINUS WELLERI VAR. LATUS n. var.

Plate XLIX, figs. 24-33.

At one locality in Cerro Gordo county, about one-half mile to the northwest of Bird Hill, Mr. C. H. Belanski found a considerable number of plates and spines which differ in some ways from the typical plates and spines assigned to *N. welleri*. The plates are relatively thinner and larger and the spines are more robust than in the latter species.

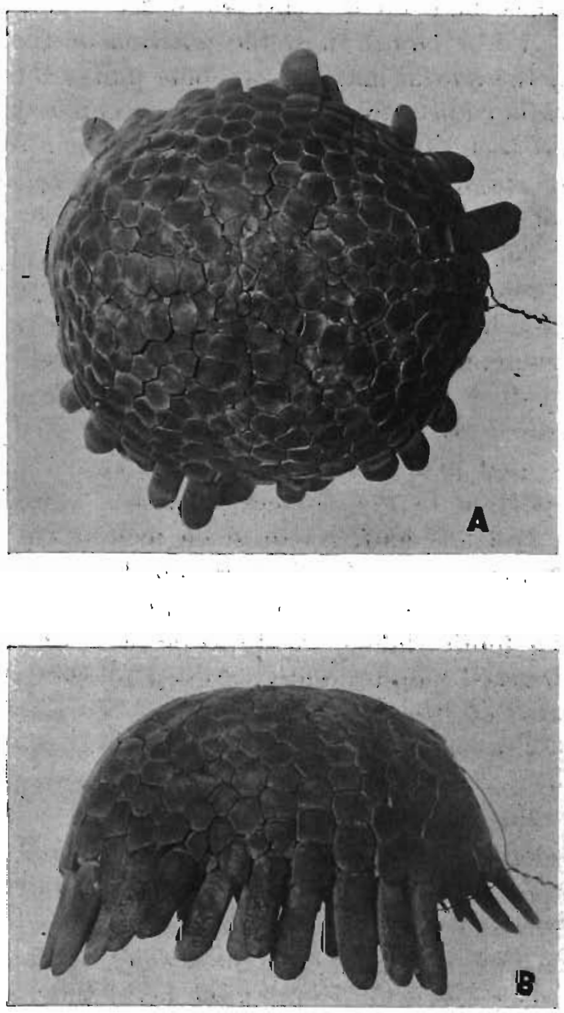

FIG. 79.—*Colobocentrotus atratus* Brandt. Apical (A) and lateral (B) views, natural size. The spines of this modern species, as in the Devonian *Nortonechinus*, are expanded distally until their polygonal surfaces form a coat of mail over the greater part of the test. The broad flattened spines of the ambital region are not like any in the test of Nortonechinus.
Pacific Ocean; Necker Island, Hawaii. Zoology Museum; C. C. Nutting, collector. (U.I.C. 18877.)

Later on the writer visited the place with Mr. Belanski and a large additional lot was obtained. No plates intermediate in size were collected, all being broader and more rounded than those of the type species. The spines are typical but are relatively larger.

NORTONECHINUS OWENENSIS n. s.

Plate L, figs. 26-35.

Species based on a large number of interambulacral plates, a lot of incomplete spines, and some parts of the lantern. They occur in a weathered marly zone in which they have been rather poorly preserved. On account of their imperfection the diagnostic characters are somewhat obscure, hence they are referred to this genus with some hesitancy.

Interambulacral plates irregular in shape, proportions of width and length variable, edges very thin; main tubercle fairly large, out of the center on most plates, perforate, faintly scrobiculate, basal terrace and other features obscure, but thought to be present. A few plates show the position of the sutures and the bevel of the adoral margin; on some plates the margin of the bevel is rather abruptly bent inward. Secondary tubercles very small and seen only on a few plates, being apparently worn away or absent on most plates. Ambulacrals unknown. Fragments of eleven spines have been found associated with the plates. They are all slender-shafted and small when compared with those of *N. welleri.* Moreover, those which preserve the apex terminate in a trident of slightly divergent spinules. Acetabulum broad, limited by a well-marked ring; base spreading to a definite annulus. Surface marked by fine longitudinal striations.

The lantern is represented by parts of three hemipyramids. They are small in proportion to the associated plates. One specimen, number 3063, is a left half, its foramen magnum is wide-angled and it has a prominent lateral wing—on the interpyramidal surface of which oblique ridges may be faintly seen; on the inner surface the tooth slide is well preserved. The outer face is noticeably curved longitudinally; a deep retractor muscle scar traverses most of the face. Dorsally are two pits of considerable size which presumably mark the position of the epiphysis. Total length, 5.5 millimeters, thickness from outer face to point of lateral wing, 3.1 millimeters.

The rather indefinite shape and featureless character of most of the plates of this species as well as the excentric position of the main tubercle do not conform closely to the regular and clear-cut outlines and marking of plates of other species of the genus. Some features, such as the position of the main tubercle, the irregular shape, and the faintly shown or absent secondaries, remind us of *Lepidocentrus* of the type of *L. eifelianus.* (See Phylogeny of the Echini, Plate 20, figure 14.) The presence of sutures and bevelled marginal borders of the *N. welleri* type on a few of the best preserved plates, however, makes reference to *Nortonechinus* more plausible.

Wherever loose plates of *N. welleri* or of *N. welleri latus* are collected, about an equal number of the large primary spines with polygonal apices are obtained. At the type locality for

N. owenensis over seventy plates were obtained and not a spine of any other type than those described above and but a few of them. Their small size and broken condition, however, make them less conspicuous than the plates and hence harder to find. Further collecting may disclose the larger spines but it is extremely unlikely.

Position and locality.—Owen substage, Lime Creek beds; in gutters along roadside between section 36, Mason township, and section 31, Portland township. The type locality is about seventy-five yards north of the wagon bridge over Owen creek near the home of Mr. Timothy E. Wagner. They occur in a weathered marly shale just beneath the thin overlying drift at a horizon about thirty-five feet above the *Idiostroma* ledge which marks the base of the Owen beds. The type locality is in Cerro Gordo county.

NORTONECHINUS STAINBROOKI n. s.

Plate XLIX, figs. 34-43; text fig. 80.

FIG. 80.—Interambulacral plate of *Nortonechinus stainbrooki* Thomas, about x3. Collected at exposure number three, Independence shale, south of Brandon, Iowa. (U. I.C.3101.)

Known only from a few primary spines and one interambulacral plate found in the Independence shales.

The interambulacral plate is of medium size, nearly uniform thickness, and strong aboral imbrication. It is rounded polygonal in outline, longer than wide, its greatest width being just adapical to the main tubercle. The marginal border is quite narrow adapically but is well developed adorally. On the adoral bevel the lateral or adradial tracts are much larger than the median tract, indicating that the imbricating plate next adoral in the column did not have large areal contact with it. The positions of the sutures are obscure except the two adoral oblique (orad-interradial) and these two are low and meet in an angle which tends to obliterate the transverse adoral suture. The adapical transverse and apicad-interradial sutures are not defined; this part of the plate is rounded and its extrascrobicular surface merges into the marginal border. The mamelon is smoothly rounded, perforate, neck straight, flush platform narrow. Basal terrace and scrobicular circle indefinite due to wear but there is a well marked scrobicule. Secondary tubercles low, scattered, practically aborted between the adoral oblique sutures and the scrobicular circle where the extra-scrobicular area is quite narrow—adorally one or two tubercles occupy the angle.

Dimensions.—Length 9.0 mm., width 8.1 mm.

The primary spines are notably short and stout. Each spine expands abruptly from the annulus to the very broad and thick apex. The base is short and there is little or no contraction above the annulus. Apices of all the specimens are sharply polygonal. Surface markings much as in *N. welleri.*

Among the hundreds of primary spines of *N. welleri* collected in Floyd and Cerro Gordo counties in the Lime Creek beds it would be difficult to select a single specimen approximating the short shafts, abrupt expansions, and relatively broad terminations of the spines of this lot from Benton county. The measurements in millimeters of five typical specimens follow:

	a	*b*	*c*	*d*	*e*
Length	4.2	5.1	5.0	4.7	6.0
Greatest width of apex	8.5	9.0	8.5	7.5	8.2

Occurrence.—Independence shale, outcrop number three, near Brandon, Iowa. Twelve spines and one plate. Here they occur with *Arthracantha mamelonifera, Douvillina variabilis, Dalmanella infera,* and other typical Independence fossils. Collected by M. A. Stainbrook.

Xenocidaris Schultze.

Genus based by Schultze upon a number of trumpet-, club-, or bell-shaped spines found in the German Devonian unassociated with any other part of the test.

The Iowa material consists of scores of spines, a half pyramid, and a single interambulacral plate with a strong central tubercle and a wide adoral bevel. Spines slender-shafted with well defined acetabulum and annulus; apical expansions variously modified as in *X. clavigera* Schultze.

The writer doubts that the spines described as *X. cylindrica* Schultze really belong to this genus since they are spindle-

shaped, covered with nodose spinules, and bear a milled ring; moreover they are much longer than the spines of the other *Xenocidaris* species, one specimen reaching a length of 55 mm.
Middle Devonian of Germany; Upper Devonian of Iowa.

XENOCIDARIS AMERICANA n. s.

Plate L, figs. 1-25.

Compare *Xenocidaris clavigera* Schultze, Monograph der Echinodermen des Eifler Kalkes, p. 14, pl. xiii, figs. 3, 3a-h, 1866; also Jackson, Phylogeny of the Echini, with a Revision of Paleozoic Species, Mem. Boston Soc. Nat. Hist., vol. 7, p. 455, text fig. 256a-d, 1912.

Interambulacral plate is irregularly polygonal but wear and breakage prevent our knowing its exact original shape. It has a prominent tubercle with a broad foramen and there is some evidence of a basal terrace and a scrobicule. The adoral bevel is wide and hollowed out transversely just below the adoral suture; the edges of the plate are thin and fragile. Greatest length, 5.8 mm., greatest width, 5.0 mm.

Spines trumpet-shaped or club-shaped, with very slender shafts especially just above the annulus, round in cross section, tapering gradually upward—the taper beginning just above the annulus in some specimens but confined to the distal half or even less in others. Each spine terminates in a more or less flat or slightly concave surface surrounded by a subcircular marginal coronet of blunt spinules which are somewhat irregularly spaced and vary from five to twelve in number; viewed from the side the spinules in many cases are seen to be continuations of ridges on the fluted surface of the expanded part of the spine. The terminal face of most specimens is at right angles to the axis of the spine but in a few it is slightly oblique; from the center of the terminal face rises a blunt rounded spinule seldom higher than the spinules of the coronet and similar to them; on a few specimens the single spinule is replaced by a central cluster of two to six spinules. Acetabulum shallowly and broadly hollowed out, suggesting a large tubercle on the corresponding plate, deeply perforated centrally, its margin bounded by a definite ring; there is a well marked annulus but no evidence of milling. The surface of the spines above the annulus is marked by exceedingly fine longitudinal striae which apparently do not continue over the apical surface, their place being taken by very fine granulations. In a little more than two hundred spines in the collection at hand only three or four specimens show any sign of compression of the apical termination as is the case with most of the spines of *Nortonechinus*. One of these is compressed on four sides into a polygon, the others are flattened on one or two sides only. The only noticeable modification as a result of the compression is the partial suppression or elimination of the marginal spinules and a tendency to develop irregularly distributed apical pustules.

Dimensions of a complete spine, number 3074, are: length, 11.5 mm.; diameter of apex, least, 3.9 mm., greatest, 4.2 mm.; diameter of base, 1.9 mm.; diameter of shaft at midlength, 1.6 mm.; height of base, 1.0 mm. Several incomplete spines indicate sizes larger than those attained by this one while many are considerably smaller.

The jaw apparatus is represented by a nearly complete left hemipyramid of interesting proportions. It is twelve millimeters in length and much less curved than those of *Devonocidaris* described on a subsequent page. On the inner face the dental slide extends about two-thirds the length of the specimen; distal part above the pyramidal suture broken away, foramen magnum evidently quite shallow; corrugations for interpyramidal muscles are very fine but can be seen over the entire surface with a hand lens. They cross the area transversely, being arched distally toward their midlength. The outer face is traversed longitudinally by a deep retractor muscle scar which extends nearly the whole length of the specimen.

The spines of this species resemble superficially some of the rounded spines of *Nortonechinus welleri*. However, the spines of *X. americana* are more slender, have a marginal coronet, are fluted in most cases, and the hollowed-out apical surfaces are not marked by fine striations. Compressed polygonal terminations are the rule in spines of *N. welleri*, the reverse condition prevails in *X. americana*. A mixed lot from the two species can be separated with ease. The poorly preserved interambulacral plate suggests a high degree of imbrication; this together with other less satisfactory characters suggest probable family relationship and both are placed in the Archeocidaridae.

Position and localities.—At the base of the marly fossiliferous shale at and just above the contact with the blue plastic shale of the Lime Creek beds. At this zone, here designated the *Xenocidaris* zone, the shale is in many places somewhat pyritic and the spines and other parts are darker in color than the fossils of beds ten feet higher. In collecting *Xenocidaris* parts it has always been kept in mind that spines and plates of *N. welleri* might be among them due to wash or slump from above. None have so far been encountered and in fact at the spots where *X. americana* have been found it happens that no finds of *N. welleri* have been made in beds exposed on the slope immediately above them. The best finds of *X. americana* have been obtained by digging out the black shale where they occur and then working it over with supplementary washing and screening. Most of the specimens for this study were obtained near the east end of the pit of the Rockford Brick and Tile Company. The places have now been worked out for clay.

LEPIDOCENTRIDAE Loven

Test spheroidal or flattened horizontally, circular in the ambital plane, pentagonal or elongate through the axis III, 5. Two columns of plates in an ambulacral area. Pore-pairs uniserial or slightly biserial. Ambulacral plates imbricating adorally and beveled strongly under the adradials. Interambulacra with numerous, five to fourteen, columns of plates in an area, moderately thin to very thin. Interambulacral plates imbricate strongly aborally and from the center outward and over the ambulacrals. Oculars are small, insert; genitals wide, low, with many pores as far as known. Lantern inclined, composed of forty pieces. (Modified after Jackson, Phylogeny of the Echini, page 284.)

DEVONOCIDARIS Thomas

1920. *Devonocidaris* Thomas. Bull. Geol. Soc. Amer., vol. 31, p. 212.

Genus known only from isolated plates, spines, and parts of the lantern found massed together in a thin bed in the marly fossiliferous zone of the Lime Creek shale.

Interambulacral plates small, very thin in proportion to area, polygonal or possibly rhombic in outline; complete plates are rare, the most perfect ones, however, are essentially five- or six-sided with little or no evidence of imbrication. Each plate bears a prominent central or subcentral tubercle, perforate, noncrenelate, and the boss is bordered by a basal terrace; no scrobicular ring of tubercles but a few scattered secondaries are present on the extrascrobicular areas of some plates. Ambulacral plates small, transversely elongate, with a terraced perforate tubercle at one end and a pair of pores near the other and narrower end. A few of these plates show evidence of imbrication. Spines slender, acicular, vertically striated. Lantern inclined and wide-angled; each tooth with a median longitudinal groove on its convex surface and a nearly smooth flat concave surface.

From *Archeocidaris* M'Coy, of the Mississippian, *Devonocidaris* differs in the absence of a definite scrobicular ring, and in having long slender spines which fit nowhere into Jackson's key to the spines of that genus. (See Phylogeny of the Echini, p. 258.) The presence of a basal terrace precludes reference to *Eocidaris* Desor. The strikingly different spines and the strong imbrication in *Nortonechinus,* herein described, exclude it from that genus. In the writer's opinion, its affinities are with *Lepidocentrus* Müller; reference to the family Lepidocentridae, however, is made with some hesitation and until at least associated interambulacrals are found throwing light on the question of imbrication the family reference can not be satisfactorily settled.

DEVONOCIDARIS JACKSONI n. s.

Plates L, 36; LI, 1-26; LII. 1-4; LIII, 1-7; LIV, 1-6.

Species founded on abundant specimens of isolated interambulacral and ambulacral plates, spines, and parts of the lantern confusedly intermingled in thin calcareous slabs on the surfaces of which the specimens are weathered out into more or less sharp relief. The parts are so delicate and fragile that any attempt to remove them from the slabs or to uncover hidden edges invites damage to the specimen; even most careful cleaning has in several cases proved disastrous. In spite of this difficulty an abundance of most of the parts has been found in excellent condition.

Interambulacral plates very thin, small, and delicate; outline polygonal, but in most cases incomplete due to the breaking away of parts of the thin edges; the general shape of the more perfect plates is hexagonal or pentagonal (adradially). No definite evidence of imbrication, hence orientation of plates is uncertain. Primary tubercles prominent, central or subcentral; mamelon round, centrally and rather deeply perforated by a round foramen, dome smooth, neck straight or slightly undercut in some specimens; flush platform narrow and without a parapet; from the platform the surface of the boss passes downward with an even or gently concave surface to a low but distinct basal terrace. Secondary tubercles irregularly distributed, one to four, rarely five, in number, some plates have none; a few of the larger secondaries are distinctly mamelonate and have a very low but obvious terrace. Tertiary tubercles showing perforations occur rarely. A few scattered granules complete the ornamentation. On a few plates (adradials) one edge is distinctly scalloped; the scallops, three or four in number, appear to be for the reception of the ends of the ambulacral plates along the adradial suture. Under side of the plates smooth. With good lens the cribriform tissue of the plates may be readily seen.

Ambulacral plates small, thin, delicate, transversely elongate in most cases and bearing a pair of subequal oval pores whose long axes converge; margins of the pores elevated into a distinct rim on most plates while on a few a well defined peripodium is present. The pore-pair lies toward the narrower end of the plate while the broader end bears subcentrally a prominent perforate tubercle which when well preserved is surrounded by a low basal terrace similar to that of the secondary tubercles of the interambulacral plates; the pores pass through the plate obliquely downward and toward the tuberculate end—as a result the pore-pair is more nearly central on the inner surface. On the inner surface of some plates there is what appears to be slight bevelling suggesting adoral imbrication but the character is not constant. Smaller plates are found with transverse diameters of one-half or less that of the ordinary ambulacrals but they are not common; these bear a pore-pair identical with the others but smaller and non-tuberculate; they are thought to be demiplates or primaries from the extremity of the ambulacrum.

Compound plates of small size, irregular shape, and delicate structure occur sparingly; they are variously perforated by four or six pores (one has five); the pores are smaller and more narrowly oval than those of the primary plates and are arranged in pairs in the form of an arc of varying degree of curvature on different plates. The apical system is represented in the collection by a subangular genital plate which bears the "madreporiform tubercle" or madreporite. The plate is pierced by two round genital pores which are about twice as far apart as either pore is from its edge of the plate measured transversely. The porous area is subcentrally located being confined to that part of the plate adapical to the two large pores but not reaching the adapical edge.

Dissociated parts of the lantern are relatively common. The lantern appears to have been strongly inclined and fairly wide-angled. No complete pyramids and only doubtfully complete hemipyramids have been seen. Foramen magnum moderately deep. Each maxilla bears a gently curved dental slide divided longitudinally into two nearly equal parts by a slender ridge which runs parallel to the symphysis, becoming more slender aborally and ending in a more or less free point—the styloid process—at a short distance below the margin of the foramen magnum. Corrugations for the attachment of the interpyramidal muscles pass inward and downward over the interpyramidal face; the peripheral face bears an elongate retractor muscle scar which is deep adorally but shallower and less well marked dorsally. Dorsal surface of the maxilla apparently smooth but preservation obscures this point in many cases, in some of which the epiphyses may be present. Teeth of a distinctly lighter color than other parts of the lantern and very well preserved except for breakage along calcite cleavage planes. Tooth gently curved, its peripheral surface traversed by three longitudinal grooves as seen in cross section; the depth of the median groove is fully one-third the thickness of the tooth; the sides and floor of this groove are rounded but in some cases almost V-shaped in section; the lateral grooves are situated one on each slope midway between the center and the thin lateral edges, they are quite shallow and appear to be counterparts of the ridges in the floor of the dental slide mentioned above; on some teeth the outer edges of the lateral grooves are so prominent that they simulate slender ridges. The inner surface of the tooth is flat; under a lens it is longitudinally marked by exceedingly fine, shallow, parallel grooves separated by broad flat intergroove areas. Dorsal end of tooth more or less forked except when broken by cleavage; tip of tooth sharply cuneate, re-enforced on the back by converging extensions of the ridges on either side of the median groove and flanked by one or two sharp denticles on each side.

Rotulas slender, upper surface rounded, under surface toward the inner end bearing a more or less well defined median ridge. Both ends notched, the inner end the deeper, the outer end the wider; as viewed from the side some of the rotulas are somewhat curved.

Spines notably slender, straight, circular in cross section, and very fragile; base short, enlarging very gradually to the rather indefinite annulus, thence a trifle more slender for a short distance above the annulus and thence gradually expanding up to the normal size. Acetabulum round and shallow. Tip of the spine uncertain, a few show a bluntly rounded apex while others taper gently to a sharp termination. Practically all spines are incomplete, but in spite of this two or three sizes are apparent corresponding to the various tubercles described above and in addition a few minute miliary spines are attached to some of the plates. Very fine longitudinal striations mark the total length of the spines, passing more or less obscurely over the annulus and base; there are twenty-five to thirty-five striations on each spine.

The following measurements taken in millimeters indicate the size and proportions of some representative parts:

Interambulacrals:	*a* on slab 3035	*b* slab 3011	*c* slab 3005	*d* slab 3012
Longest meridional diameter	2.9	2.5	3.7	3.6
Meridional diameter through primary tubercle	2.7	—	3.5	3.5
Longest transverse diameter	3.4	4.4	3.2	4.1
Diameter basal terrace	1.1	1.2	1.1	1.25
Diameter of mamelon	0.4	—	0.32	0.5
Diameter of foramen	0.15	—	0.12	0.2

Note: Interambulacrals *a*, *c*, and *d* are apparently adradials; *b* is a hexagonal plate. Each specimen is marked by a double ink ring on the slab.

Ambulacrals:	*a* slab 3013	*b* slab 3013	*c* slab 3013
Meridional diameter through tubercle	1.5	1.6	1.5
Meridional diameter between pores	1.1	1.1	1.2
Greatest transverse diameter	3.0	3.1	2.6
Distance from center to center of pores	0.5	0.6	0.5
Length of pore	0.6	0.5	0.6
Diameter of basal terrace	0.8	0.9	0.8

Demiplates:	*a*	*b*
Meridional diameter between pores	0.7	0.6
Greatest transverse diameter	0.8	1.5
Distance from center to center of pores	0.5	0.4
Length of pore	0.3	0.2

Note: Both plates are on slab 3001; *a* is in a double ink ring and *b* is near the edge.

Compound ambulacrals: Two diameters taken at right angles to each other on specimen *a*, slab 3010, are 2.4 and 4.5 mm.; specimen *b*, slab 3001, near the catalog number, has similar diameters of 0.4 and 1.4 mm.

Madreporic genital plate, on slab 3001.

Meridional diameter between the pores	1.2
Greatest transverse diameter	1.5
Distance from center to center of pores	0.8
Madreporic area	0.5 x 0.7

Sieve-pores about 14 in space of one millimeter.

Maxillae:	*a* slab 3001	*b* slab 3024	*c* slab 3004	*d* vial 3024
Greatest height	3.7	3.0	3.0	5.5
Greatest width	2.4	1.7	2.0	2.4
Length of œsophageal margin	2.4	1.7	2.0	3.2
Length of symphysis		1.9		
Width of dental slide		0.6		0.9
Corrugations	6 in. 1mm.	6.3 in 1mm.		

Teeth (specimens incomplete):	*a* slab 3020	*b* slab 3029	*c* slab 3013	*d* slab 3001
Length	4.7	3.5	3.0	3.0+
Width	1.9	1.0	0.9	1.03
Length of the tip	1.0	0.6		0.7

Braces: specimen *a*, slab 3031, near edge, length 4.1; width 1.3.
specimen *b*, vial 3925, longest one, length 4,0; width 1.0.
specimen *c*, slab 3001, near edge, length 2.3; width 0.6.
specimen *d*, slab 3016, length 2.6; width 0.7.

Spines (incomplete);		length	diameter	diameter of annulus
a,	slab 3003,	11.4	0.3	0.5
b,	slab 3032,	9.4	0.4	
c,	slab 3003,	5.1	0.2	0.3
d,	slab 3003,	7.2	0.3	0.35
e,	slab 3003,	10.6	0.2	0.3
f,	slab 3008,	2.8	0.02	0.022

The species is named in honor of Dr. Robert Tracy Jackson whose classic monograph on the "Phylogeny of the Echini, with a Revision of Paleozoic Species" has proved very valuable in the present study.

Position and localities.—Near the middle of the marly fossiliferous zone of the Lime Creek shale. The best specimens were obtained in gutters along the roadside about half way up Bird Hill, west edge of section 19, township 95 north, range 18 west. Also in the *Devonocidaris* horizon on the hills to the west and northwest of Rockford.

Explanation of Plates.

The illustrations on the following plates are all natural size unless otherwise indicated. The catalog number of all specimens in the University of Iowa collection is given in parentheses following the letters U. I. C. The location of other specimens illustrated is given in so far as it is known.

PLATE XXXV.

Figs. 1-11, 13, 18. *Strobilocystites calvini* White.

1. Oral view of the type specimen, natural size. 2. The same view x2. 3. Same specimen showing right rhomb and right anterior ambulacrum x1.5. 4. Same as figure 3 but turned slightly to the right, x2. Iowa City, S. Calvin. (U. I. C. 3503.)

5. Oral view of a nearly spherical example found near Iowa City. (Cornell College Museum.) 6. Thecal plate *14* found loose at Brandon. (U. I. C. 3509.) 7. Young individual. Iowa City, S. Calvin. (U. I. C. 3504.) 8. Imperfect calyx lacking the ambulacral plates but preserving the stem. Linder's Boathouse. (Fitzpatrick Collection.) 9. A badly crushed calyx with much branched ambulacra. Brandon, M. A. Stainbrook. (U. I. C. 3508.) 10. Stem x2, assumed to belong to this species. Brandon, A. O. Thomas. (U. I. C. 3510.) 11. Drawing of plate *23* showing hydropore and the double madreporite, after specimen 3502; about x5. This and figure 13 drawn by Mr. O. T. Walter. 13. Inner and outer cycles of plates forming the anal pyramid, about x6.7. One plate in the outer cycle missing. After specimen 3501; Sanders Quarry, T. J. Fitzpatrick. 18. Oral view of a large and somewhat damaged calyx showing madreporites and hydropore, about x1.5. Vinton, secured by W. S. Glock. (U. I. C. 3502.)

Figs. 12, 19-21. *Strobilocystites schucherti* Thomas.

12. View of left side showing pectinirhomb *12-18*, the sutures, and the relatively smooth plates, about x2. Nora Springs, C. H. Belanski. (U. I. C. 3505.)

19 Anal view of another example x2. Nora Springs, C. H. B. (U. I. C. 3506.) 20, 21. Left and oral views of a partly crushed specimen, about x1.5. Note the elevated ambulacra, the absence of branches, and the hydropore. Near Solon, L. P. Elliott. (U. I. C. 3507.)

Figs. 14-17. *Strobilocystites polleyi* Calvin.

14. Antanal view of the holotype showing pectinirhomb *1-5* and the sutures; about natural size. Drawing by Mr. Frank Bond.

15, 16, 17. Basal, anterior, and right ambulacral aspects of the holotype x2. Ambulacral plates are missing. Cedar county, J. F. Polley. (U. I. C. 3500.)

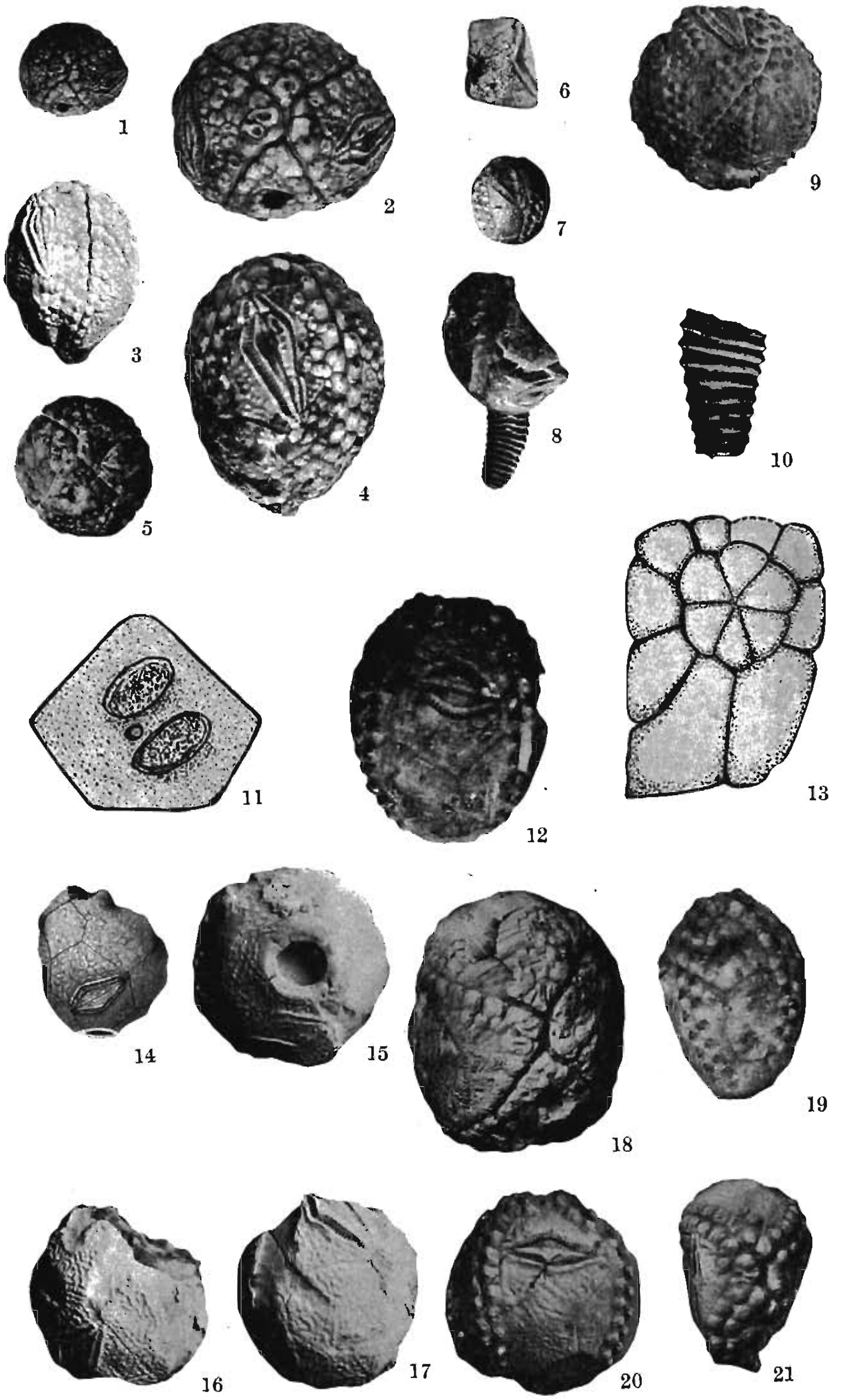
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PLATE XXXVI.

Figs. 1, 6-9, 16, 17. *Nucleocrinus obovatus* (Barris).

1. Left posterior view of an elongate calyx. One of Barris' types. Locality uncertain. (Museum Davenport Acad. Sci.)

6, 7. Anterior and basal views of a nearly perfect specimen, about x2. Sutures traced with ink. Iowa City, Frank Bond. (U. I. C. 3200.)

8, 16, 17. Left posterior side, about x2; posterior and oral views of a small, probably young, individual. Alpena, Michigan, W. H. Barris. (U. I. C. 3205.)

9. Left anterior aspect of a fine specimen. Alpena, W. H. B. (U. I. C. 3006.)

Figs. 2-5, 12, 18. *Nucleocrinus bondi* Thomas.

2, 3, 12. Left anterior, oral, and posterior views of a very perfect calyx. Linder's Boathouse, Anton Linder. (Fitzpatrick Coll.)

4, 5. Oral and left posterior views of the type, x2 and about x1.3 respectively. Near Iowa City, Frank Bond. (U. I. C. 3201.)

18. A stout but distorted calyx referred to this species. Rapid Creek, Carl Linder. (Fitzpatrick Coll.)

Figs. 10, 11. *Nucleocrinus meloniformis* (Barris).

10. Posterior view showing strongly elevated interambulacrum.

11. Left posterior ambulacral view of the same specimen x2. Waterfowl Bay, Michigan, W. H. Barris. (U. I. C. 3203.)

Figs. 13, 14. *Codaster gracilis* (Wachsmuth).

Lateral and oral views of two specimens introduced for comparison with the next. Alpena, Michigan, W. H. B. (U. I. C. 3208 a, b.)

Fig. 15. *Codaster subtruncatus* (Hall).

Lateral view, after Hall. Buffalo, Iowa.

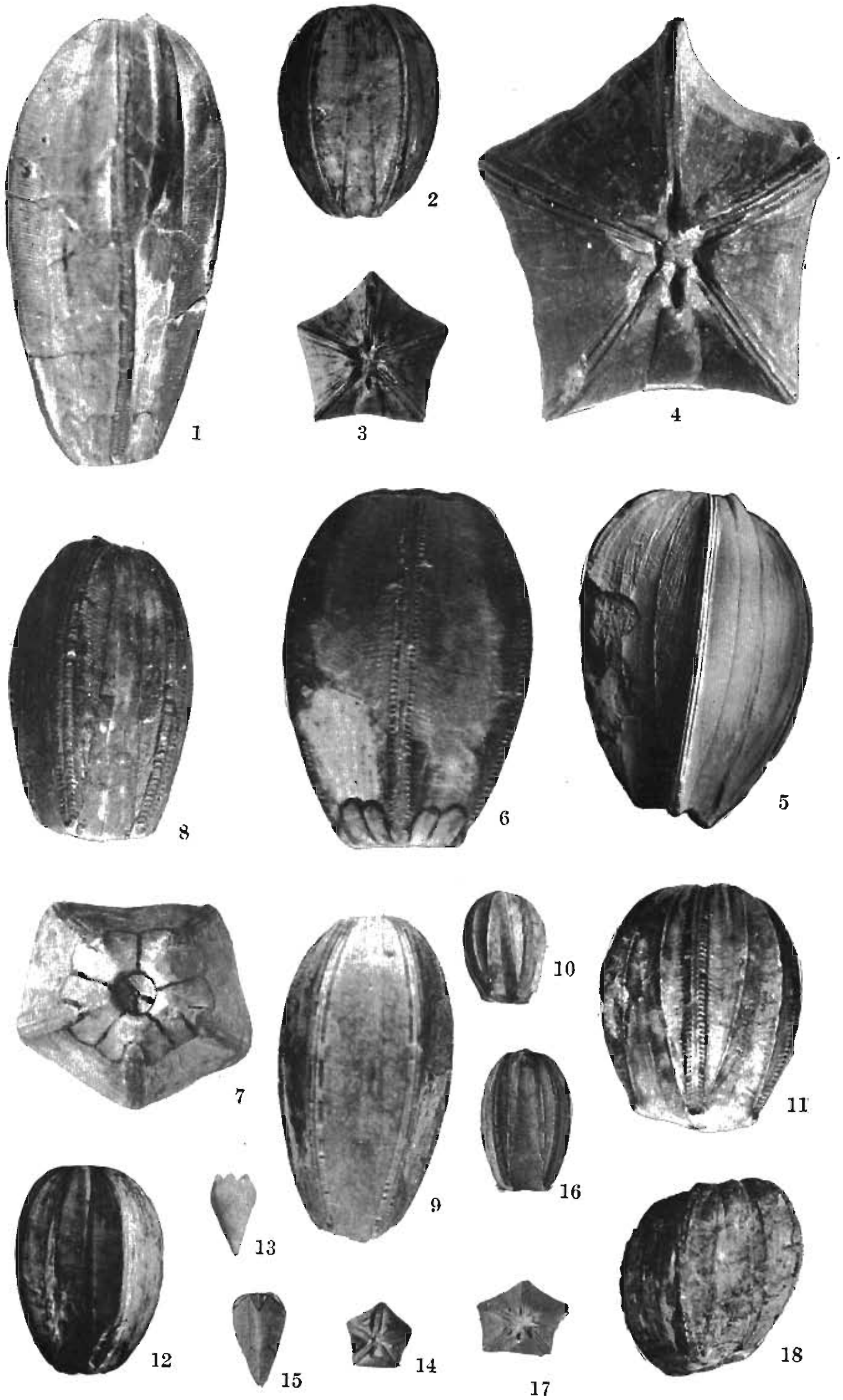
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PLATE XXXVII.

Fig. 1. *Melocrinus nodosus* Hall.

View of "right anterior ray." After Whitfield.

Figs. 2-4. *Melocrinus nodosus irregularis* Thomas.

2. Posterior aspect of the type showing plates of the anal interray. 3, 4. Basal and ventral views of the same. Brandon, M. A. Stainbrook. (U. I. C. 3600.)

Fig. 5. *Melocrinus tiffanyi* Wachsmuth and Springer.

Right posterior view of the type, after Wachsmuth and Springer.

Figs. 6-8. *Melocrinus calvini* Wachsmuth and Springer.

6. View of the left anterior ray. 7. Anterior aspect x1.4. 8. A figure after Wachsmuth and Springer. All are views of the holotype. Solon, S. Calvin. (U. I C. 3601.)

Figs. 9, 10. *Melocrinus (?) linderi* Thomas.

Two views showing the spinosity of the plates and the shape of the imperfect calyx of the holotype. On the right hand side of figure 10 the outline of the plates has been traced on the exfoliated and silicified surface. North of Iowa City, Mary Linder. (Fitzpatrick Coll.)

Figs. 11-16. *Melocrinus belanskii* Thomas.

11. Type specimen seen from the right side. 12. Basal view showing the abnormal radial cycle, about x2. Near Bird Hill, C. H. Belanski. (U. I. C. 3602.)

13. Radial plate x2, from the type locality. (U. I. C. 3751.) Figure inadvertently turned on its side by the engraver.

14. Figure showing the inner surface of a plate; slightly enlarged. Note the irregularly disposed nodes and ridges; these occur on all plates examined.

15, 16. Fragments of a stem attached to the clayey matrix, and view of a joint face. These occur abundantly with the loose plates and are assumed to belong to this species. (U. I. C. 3750 and 3752.)

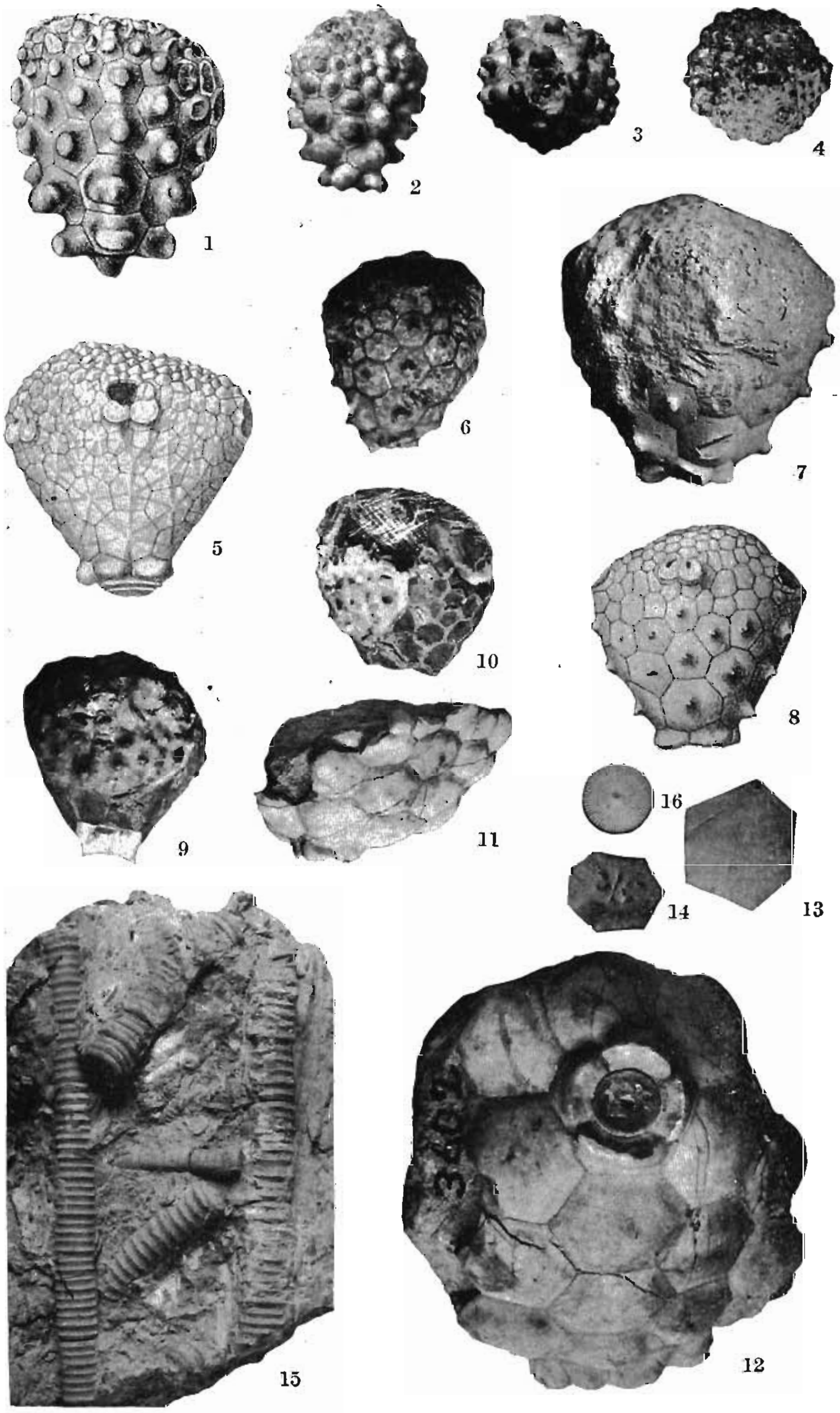
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PLATE XXXVIII.

Figs. 1-3. *Stereocrinus triangulatus* Barris.

1, 2. Basal and side views of the type, after Wachsmuth and Springer. 3. An imperfect specimen preserving the basals, the radials, and a few plates beyond them. The characteristic markings of the species are well shown. North of Iowa City. (T. J. Fitzpatrick Coll.)

Figs. 4, 5. *Stereocrinus littletonensis* Thomas.

Basal and lateral views of the holotype. Littleton, S. Calvin. (U. I. C. 3627.)

Figs. 6-12. *Megistocrinus farnsworthi* White.

6-9. Posterior, left anterior, tegminal, and basal views of the better of the two cotypes. 10, 11. Tegminal and basal views of the other cotype which is crushed but preserves a portion of the stem; orientation uncertain. Both specimens from near Iowa City, P. J. Farnsworth. (U. I. C. 3621 and 3622.)

12. Basal view of a somewhat damaged but typical calyx. North of Iowa City, Walter V. Searight. (U. I. C. 3753.)

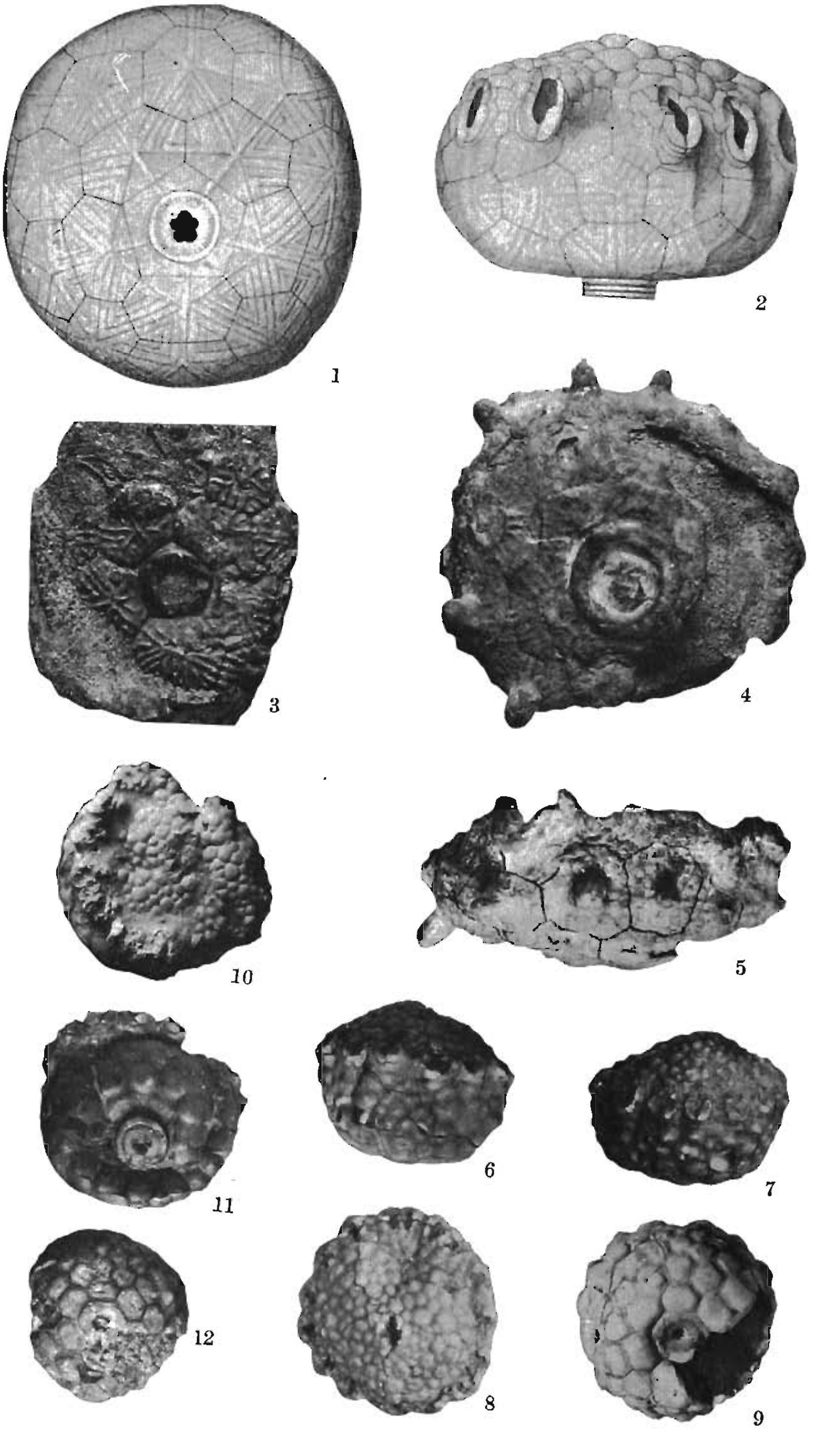
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PLATE XXXIX.

Figs. 1-5. *Megistocrinus robustus* Thomas.

1-3. Right lateral, tegminal, and basal views of the type specimen. Solon, S. Calvin. (U. I. C. 3604.)

4, 5. Right posterior and basal aspects of a smaller specimen. Solon, S. Calvin. (U. I. C. 3614.)

Figs. 6, 7. *Megistocrinus fitzpatricki* Thomas.

6. Basal view of the type.

7. View from the anal side of another specimen which lacks the tegmen. Both specimens from Linder's Boathouse. (Fitzpatrick Coll.) See also Plate XLVI, figures 10, 11.

Fig. 8. *Megistocrinus concavus* Wachsmuth.

Basal view of a typical specimen introduced for comparison. From Devonian at Alpena, Michigan. (U. I C. 3671.)

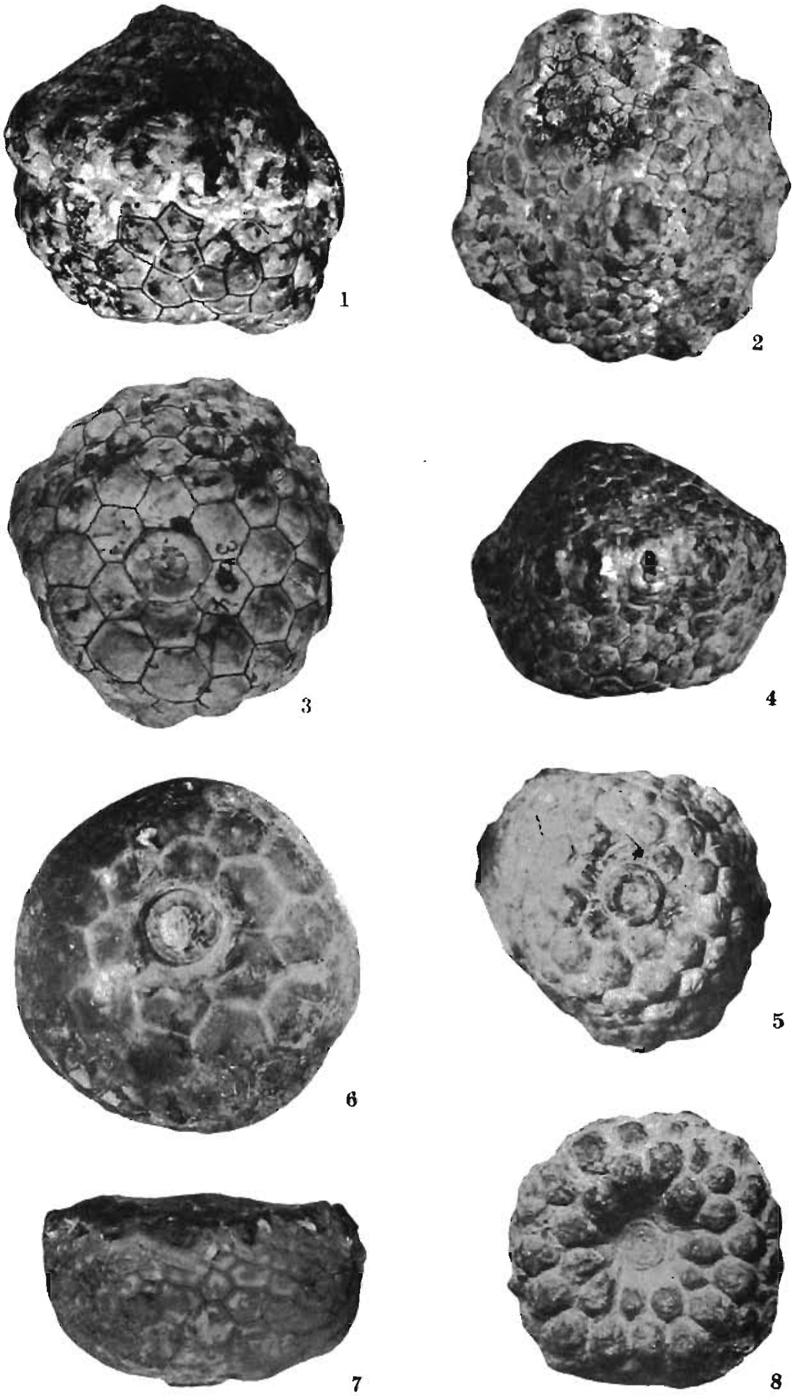
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PLATE XL.

Figs. 1-8. *Megistocrinus clarkei* Thomas.

1, 2. A left anterior and an anterior view of the type specimen preserving parts of six of the arms and a piece of the stem. (U. I. C. 3668.)

3. A much silicified individual with a somewhat higher tegmen than on average specimens. (U. I. C. 3626a.)

4. Tegminal view of an individual showing the *Platyceras* scar and the anal aperture. A part of the parasite's shell remains along the upper border of the scar as seen in the figure. (U. I. C. 3669.)

5, 6. Tegminal views of two other specimens showing the *Platyceras* scars. (U. I. C. 3626 and 3667.)

7, 8. Two views of a specimen preserving the shell of the gastropod, *Platyceras inoptatum* Thomas. The adaptation of the margin of the shell to the irregularities of the tegmen is remarkable. (U. I. C. 3623.)

All the specimens from Waterloo. Collected by Mrs. David Brant. See also Plate XLVI, figure 9.

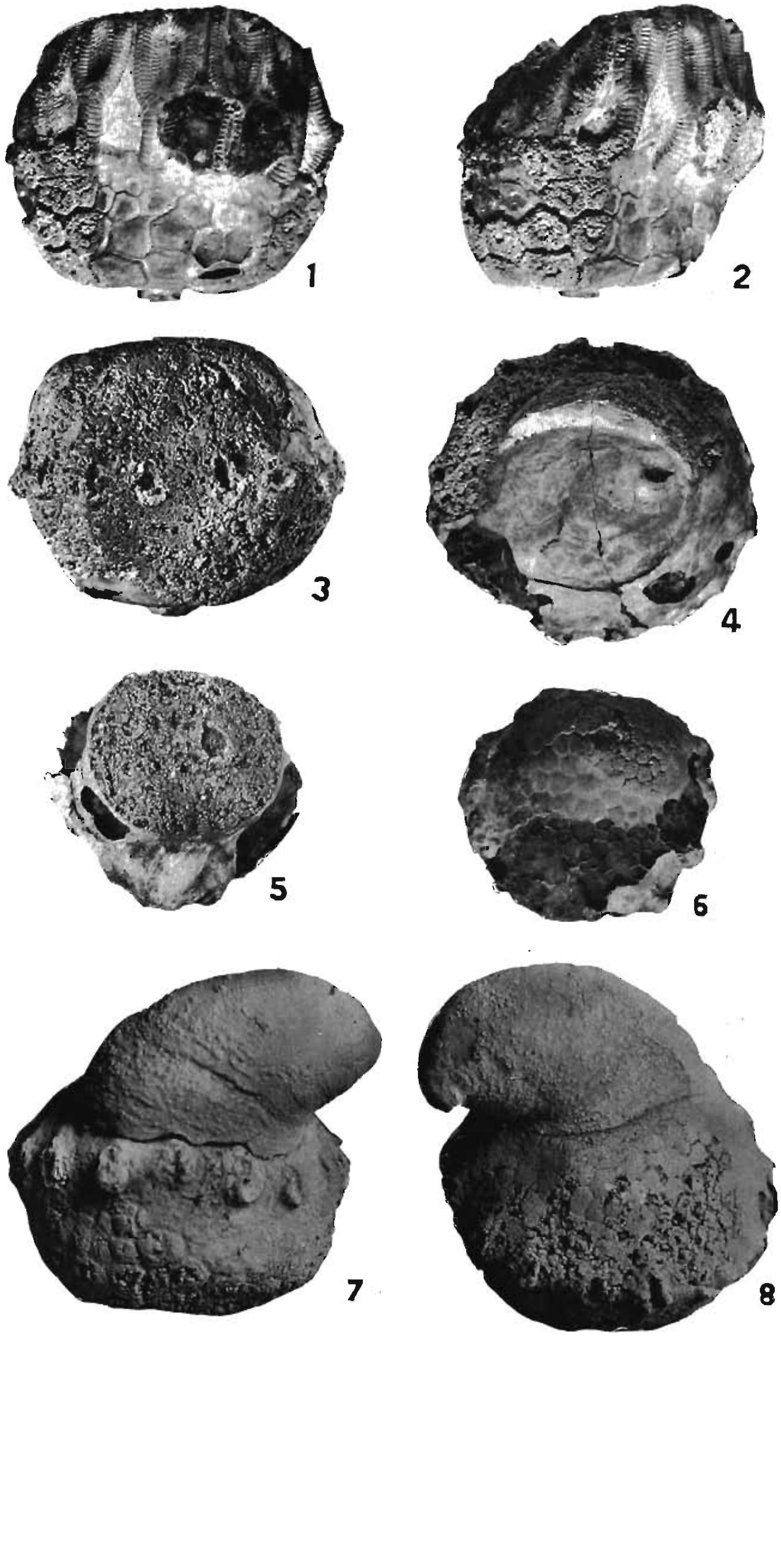
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PLATE XLI.

Fig. 1. *Megistocrinus latus* Hall.

Basal aspect of a calyx which lacks the arms and the tegmen. The anterior side is wider than the posterior in this individual. Iowa City, L. P. Elliott. (U. I. C. 3603.) See also Plate XLV, figure 3.

Figs. 2-4. *Megistocrinus nodosus* Barris.

2. Lateral aspect of a very perfect specimen which preserves a part of the stem. 3. Tegminal view of same specimen. 4. Lateral view of a smaller and younger individual. Both specimens from Alpena, Michigan, W. H. Barris. (Mus. Davenport Acad. Sci.)

Figs. 5-23. *Megistocrinus pernodosus* Thomas.

5. A set of united basals. Brandon, A. O. Thomas. (U. I. C. 3737.) 5a. Diagram of basals, x3; proportions after figure 5, by O. T. Walter. 6, 7. Lateral and dorsal views of an anchylosed set of BB to which is attached a nodose radial, x2. Brandon, A. O. T. (U. I. C. 3726.) 8-10. Side views, x2, of three plates showing height of the nodes and the constriction toward their bases; number 9 is from a curved part of the calyx wall. 11-17. Outer or dorsal view of several plates illustrating the extent to which the nodes cover their surfaces. All x2. Brandon, A. O. Thomas and M. A. Stainbrook. (U. I. C. 3727-3736.) 18-23. Stem segments from the type locality assumed to belong to this species. Natural size. Brandon, A. O. Thomas. (U. I. C. 3745-3750.)

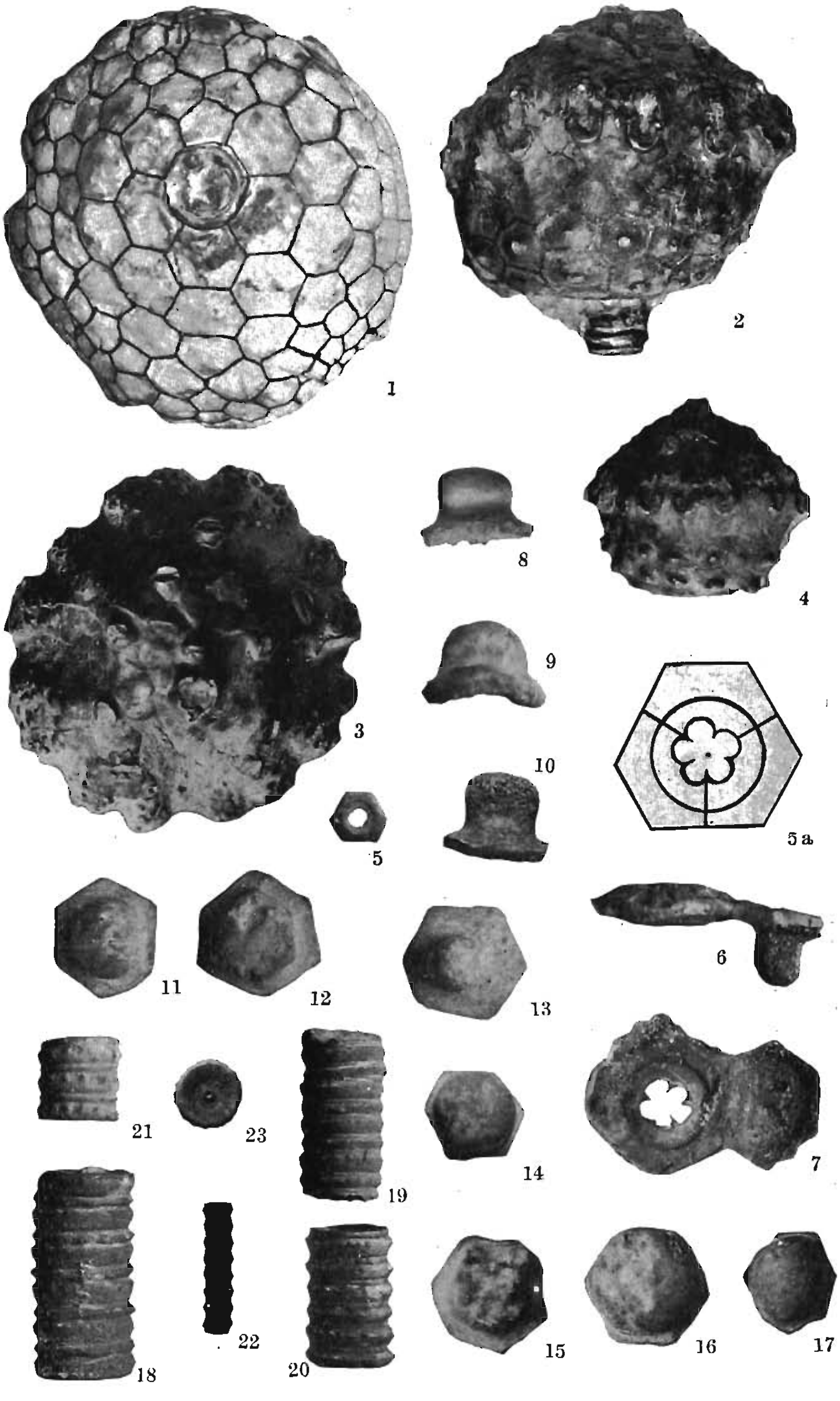
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PLATE XLII.

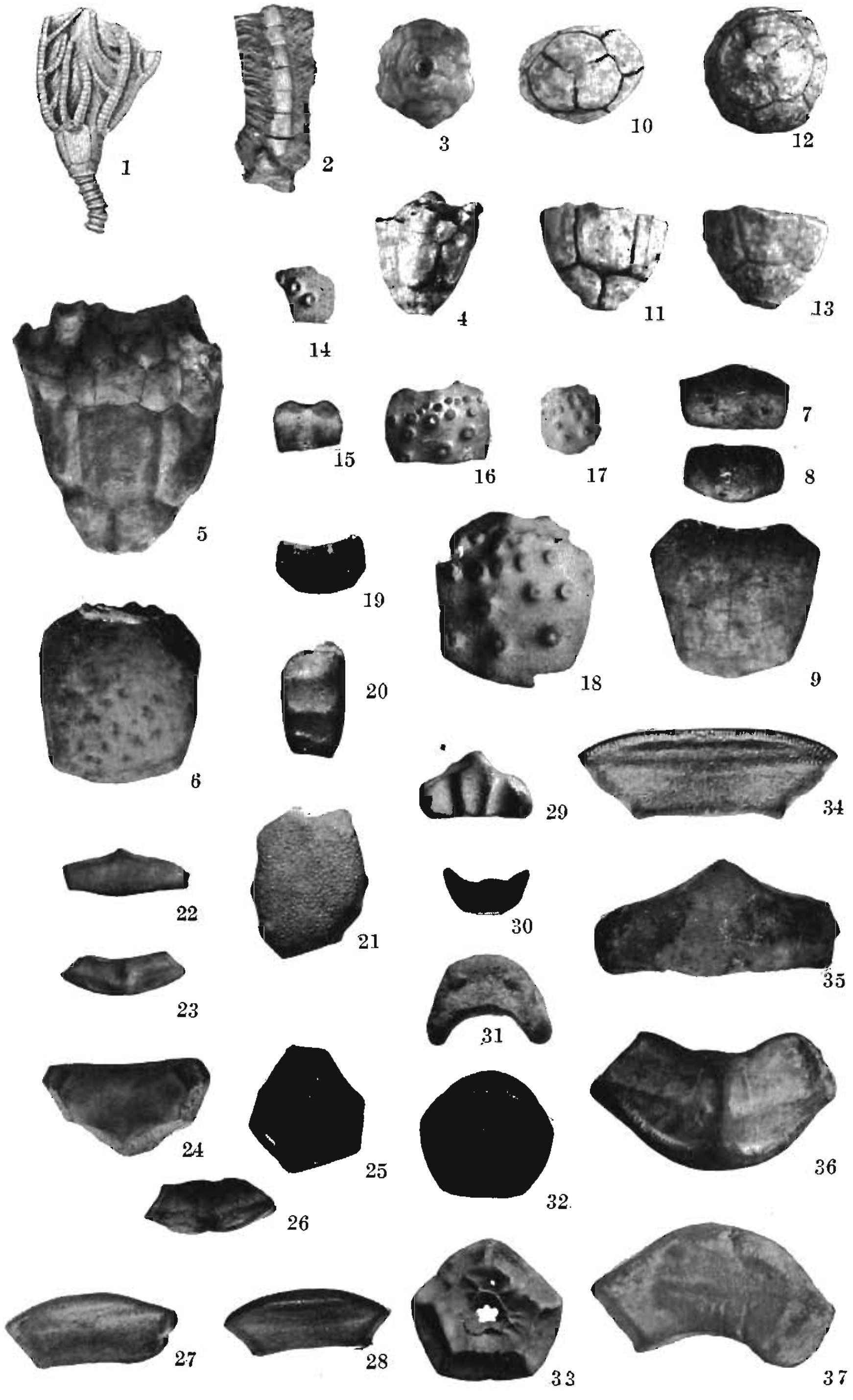
Fig. 1. *Hexacrinus occidentalis* Wachsmuth and Springer.
Anterior view of the type specimen after Wachsmuth and Springer. Davenport, W. H. Barris. (Museum Davenport Academy Science.)

Figs. 2-9. *Hexacrinus springeri* Thomas.
2. A portion of an arm preserving the pinnules, assumed to belong to this species. Type locality, C. H. Belanski. (U. I. C. 3722.) 3-5. Basal, left anterior, and anal views of the type specimen, the last figure about x2. South of Nora Springs, C. H. B. (U. I. C. 3631.) 6. A large radial preserving a part of IBr_1 in the facet, x2. Type locality, A. O. Thomas. (U. I. C. 3723.) 7-9. A radial and two IBr arranged in natural sequence. Along Shell Rock river, C. H. B. (U. I. C. 3724.) Twice natural size.

Figs. 10-13. *Hexacrinus iowensis* Thomas.
10, 11. Basal and side views of the type. (U. I. C. 3708.) 12, 13. Basal and side views of the cotype. Note that one basal plate is fully as large as the other two combined. (U. I. C. 3707.) Both from near Nora Springs, C. H. Belanski. All the figures about x2.

Figs. 14-18. *Arthracantha mamelonifera* Thomas.
14. Broken radial plate. Independence, S. Calvin. (U. I. C. 3721.) 15, 16. Ventral and dorsal views of the type, the latter view x2. It is an imperfect radial plate. Brandon, A. O. Thomas. (U. I. C. 3720.) 17, 18. Two views of a radial plate, the second view about x2.5. Brandon, M. A. Stainbrook. (U. I. C. 3719.)

Figs. 19-34. *Clidochirus iowensis* Thomas.
19. Dorsal view of a IIBr. 20, 21. Lateral view, showing thickness and facets, and a dorsal view showing granular surface; the views are x2 and x3 respectively. The plate is an interradial probably from the anal series. (U. I. C. 3705a.) 22, 23. Dorsal and distal views of IAx. 24. Ventral or inner view of a radial, x2. (U. I. C. 3700b.) 25. Ventral view of a basal x2, orientation uncertain. (U. I. C. 3674d.) 26. Distal view of a IAx. 27, 28. Proximal aspect of two IBr plates, x2 (U. I. C. 3701a and 3701b.) 29. Ventral view of a IIAx or IIIAx, x3. (U. I. C. 3672a.) 30, 31. Distal and proximal views of two IIBr showing shape, curvature, and articulation, x2 and x3 respectively. (U. I. C. 3704e and 3704c.) 32. IBB showing extension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beyond the column, the bounding rim, flat stem facet, and lumen, x3. (U. I. C. 3673f.) 33. A set of IBB showing the trilobate funnel, articulating facets, and other features, x3. (U. I. C. 3673b.) 34. Proximal view of a IBr; note its thickness, articulating grooves, and milled edge, x3; figure 27, Plate XLIII is the same specimen. (U. I. C. 3701c.)

Rockford, Bird Hill, and Hackberry Grove, C. H. Belanski and A. O. Thomas.

Figs. 35-37. *Clidochirus maximus* Thomas.

Dorsal, distal, and proximal views of the type specimen, about x2. Brandon, A. O. Thomas. (U. I. C. 3706.)

PLATE XLIII.

Figs. 1-9. *Hexacrinus springeri* Thomas.

A full complement of basals and radials found as scattered plates, about x2. Nora Springs, C. H. Belanski. (U. I. C. 3725.) See also Plate XLII, figs. 2-9.

Figs. 10-44. *Clidochirus iowensis* Thomas.

10-14. A series of IIBr, or possibly IIIBr, two of them are Ax. (U. I. C. 3704a-e.)

15-19. A series of IIBr. (U. I. C. 3703a-e.)

20-24. A series of IAx. (U. I. C. 3702a-e.)

25-29. Five IBr. (U. I. C. 3701a-e.)

30, 34. Two iBr plates; these have four facets on each side, the distal depression is not a true facet. Figures 20, 21, Plate XLII, are illustrations of the same specimen as figure 34. (U. I. C. 3705a and 3705b.)

31-33. Three radial plates. (U. I. C. 3700a-c.)

35-39. A series of basals showing variation in shape and size. (U. I. C. 3674a-e.)

40-44. Five sets of IBB, showing the trilobate funnel, the pentalobate lumen, and the bounding ridges of the facets. (U. I. C. 3673a-e.)

These thirty-five plates and combined IBB are offered as the type material of this species. The selection is made from a series of several hundred plates collected by C. H. Belanski and the author at Bird Hill and vicinity. All are about x2.

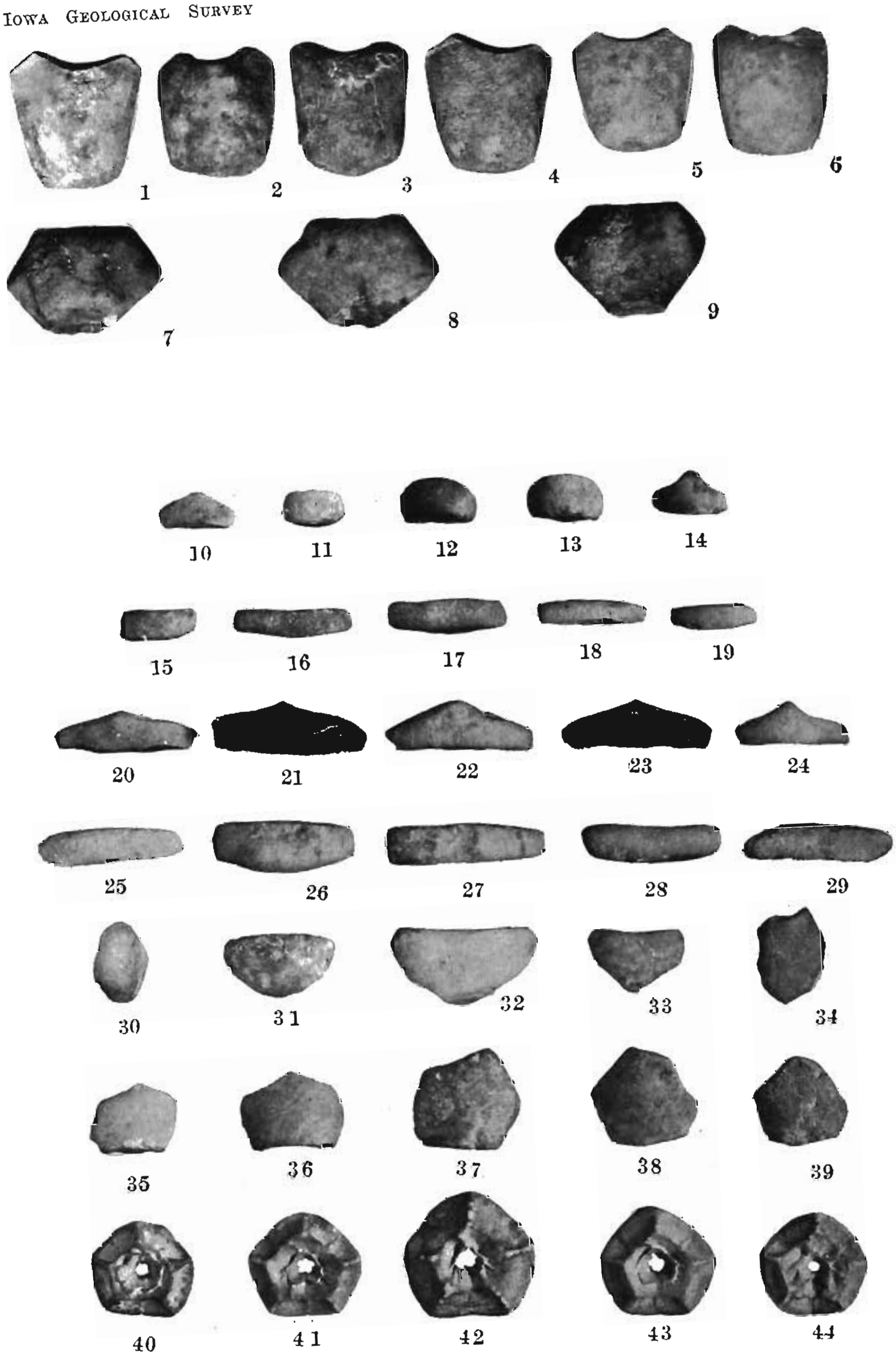
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PLATE XLIV.

Figs. 1-5. *Dactylocrinus stellatimbasalis* Thomas.

1. A view of the right posterior ray, x3.6, showing the bifurcations. 2-4. Right posterior interradial, anal, and basal views, about x2.5; the last shows the excavate base partly filled by the stem; note also the star-shaped figure made by the basals. 5. Anal view, x1.5. All are views of the holotype. (U. I. C. 3709.) Near Bird Hill, C. H. B.

Figs. 6, 7. *Dactylocrinus concavus* (Rowley).

Posterior and basal views of one of Rowley's cotypes from Devonian, Callaway Co., Mo. Figures copied for comparison from Plate xli, figures 7a and 7c, Crinoidea Flexibilia.

Fig. 8. *Euryocrinus barrisi* Springer.

Right anterior view of a specimen from Buffalo. Collected by W. H. Barris and now in the Springer Collection. The species occurs also near Alpena, Michigan. After Springer, Crin. Flex., Pl. xl, fig. 3.

Fig. 9. *Synbathocrinus matutinus* Hall.

A view of the type specimen after Hall in Geol. Surv. Iowa, vol. I, part ii, Plate I, fig. 2, 1858. Buffalo.

Fig. 10. *Taxocrinus interscapularis* Hall

A view of the type after Springer, Crin. Flex. Plate lii, fig. 6. Buffalo. Specimen in Univ. of Ill. collection.

Figs. 11-16. *Cyathocrinus rockfordensis* Thomas.

11, 12 and 15, 16. Ventral and dorsal views respectively of two radials showing the facets and the ambulacral notches, about x2. Near Rockford, A. O. Thomas and C. H. Belanski. (U. I. C. 3759 and 3760.)

13, 14. Two other specimens, about x2. (U. I. C. 3757 and 3758.)

Figs. 17, 18. *Eutaxocrinus gracilis* (Meek and Worthen).

Two views of the type; University of Illinois collection. Buffalo, A. H. Worthen. After Springer, Crin. Flex., Plate xlix, 8a, 8b.

Fig. 19. *Poteriocrinus buffaloënsis* Worthen.

Anterior view of the type specimen. Buffalo, A. H. Worthen. After Geol. Surv. Ill. vol. viii, Plate 12, fig. 1.

Figs. 20, 21. *Deltacrinus barrisi* (Worthen).

Two views, about x2, of an imperfect specimen, showing stem facet and suture lines. Davenport, W. H. Barris. (Museum Davenport Academy of Science.)

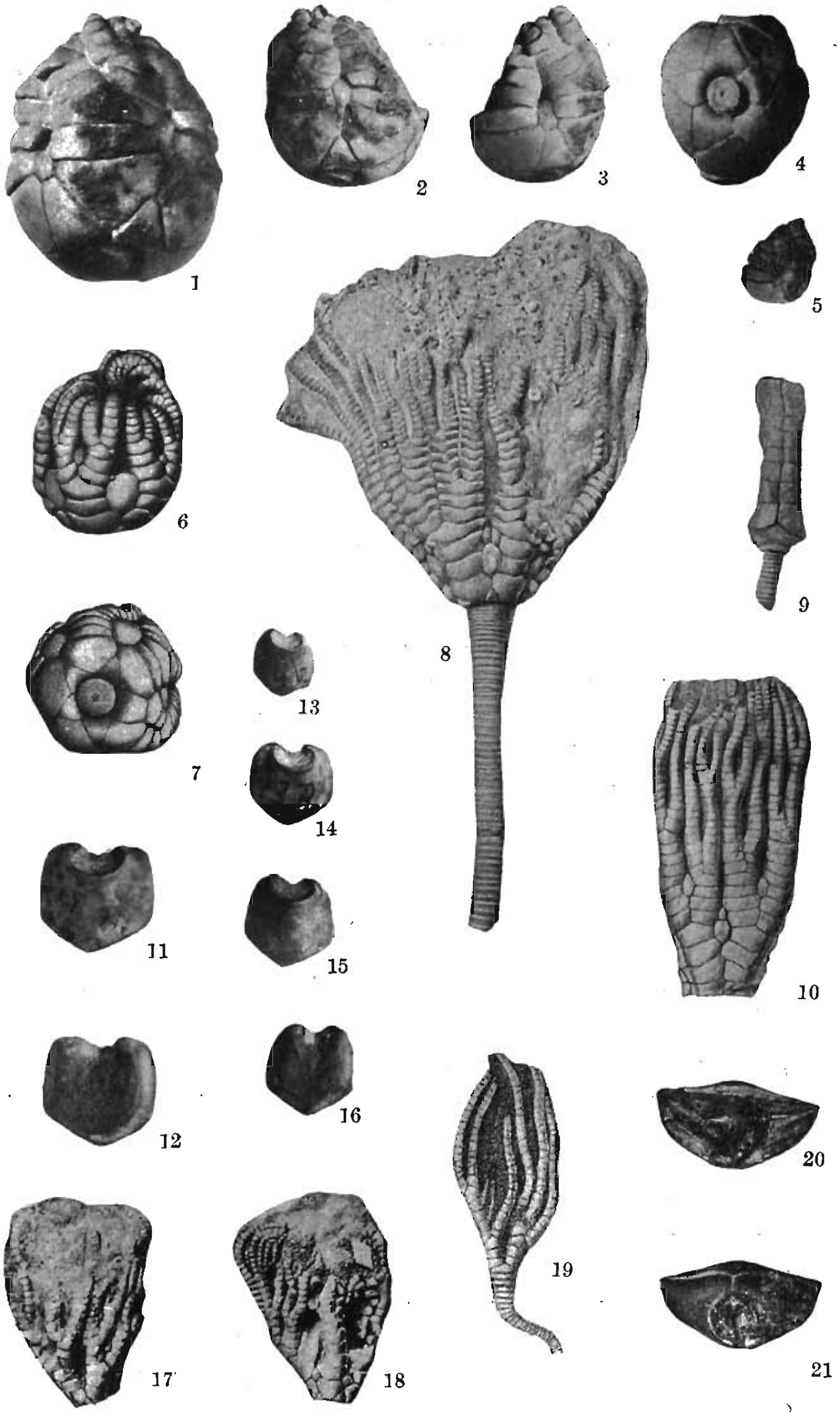
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PLATE XLV.

Fig. 1. *Decadocrinus vintonensis* Thomas.

The type specimen preserving the arms and a piece of the stem, about x2. Near Vinton, E. P. Whipple. (U. I. C. 3630.)

Fig. 2. Crinoid preserving arms and pinnules but split through in such a way as to destroy the calyx. *Megistocrinus* beds (?) near Solon, Lloyd North. (U. I. C. 3761.)

Fig. 3. *Megistocrinus latus* Hall.

A specimen preserving nearly three cycles of the smooth plates characteristic of this species. Upper levels of Linwood Quarry, below Davenport, U. A. Hauber. (Museum of St. Ambrose College.) See also Plate XLI, figure 1.

Figs. 4-6. Crinoid stem fragments.

Number 6 evidently is a large segment from a stem similar to number 4; note the hublike protrusion made up of a number of very thin columnals. Number 5 is remarkable for the rows of elongate nodes along the peripheries of its thin columnals. Bird Hill, Lime Creek shale, A. O. Thomas. (U. I. C. 3764 a, b, c.)

Fig. 7. *Megistocrinus merrilli* Thomas.

Basal view showing three cycles of plates. Note the low nodes on the IBr and iBr plates. Orientation assumed to be correct. One and one-fourth miles southwest of Brandon, M. A. Stainbrook. (U. I. C. 3762.)

Fig. 8. Crinoid stem, joint face x2.2. Compare *Megistocrinus*.

Common in *Hexacrinus* zone south of Nora Springs, C. H. Belanski. (U. I. C. 3739d.)

Figs. 9-10. Crinoid stems showing joint faces x3.

The joint face is a rounded pentagon in outline. Floors of the sectors are slightly depressed and the arrangement of the crenellae is quite unique. Lumen pentagonal.

Associated with the plates of *Hexacrinus springeri*, south of Nora Springs, C. H. Belanski and A. O. Thomas. (U. I. C. 3715c, d.)

Fig. 11. Crinoidal limestone.

Devonian, Cerro Gordo county, A. O. Thomas. (U. I. C. 3765.)

Fig. 12. *Euryocrinus* cf. *barrisi* Springer.

Fragment of a calyx from a ravine below Davenport, U. A. Hauber. (U. I. C. 3763.) See also Plate XLIV, fig. 8.

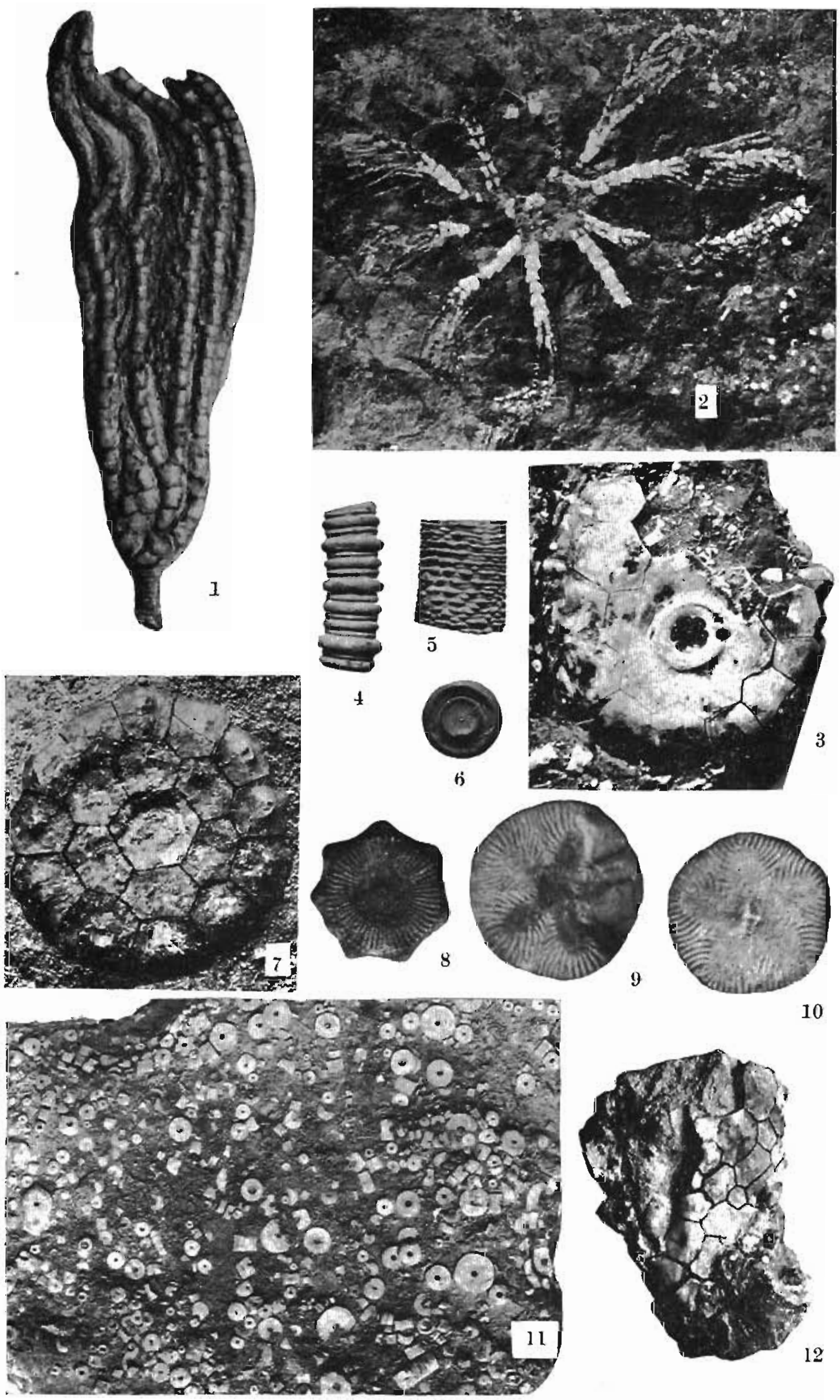
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PLATE XLVI.

Figs. 1-5. *Agelacrinites hanoveri* Thomas.

1. A large specimen, peripheral wall nearly intact, thecal plates and rays only partly preserved. (U. I. C. 3523a.)

2. A smaller specimen on same substratum as number one; imperfectly preserved. (U. I. C. 3523b.)

3. A small individual showing two solar and three contrasolar rays and the position of the anal pyramid; thecal plates lost, cover plates obscure, x2. (U. I. C. 3522.)

4. Specimen preserving thecal and wall plates showing imbrication; cover plates of arms can be made out in one or two places, x2. (U. I. C. 3521.)

5. A sector of the last tilted to show plates of the peripheral wall, x3.5.

Fig. 6. *Agelacrinites* sp.

A specimen attached to the shell of a brachiopod. Thecal and cover plates present but jumbled out of position. Brandon, M. A. Stainbrook. (U. I. C. 3524.)

Fig. 7. Crinoidal limestone.

A polished fragment from a zone near Linder's Boathouse, left bank of Iowa river, about six feet above low water as controlled by the Coralville dam, A. O. Thomas. (U. I. C. 3767a.)

Fig. 8. Slab on which are a number of long, slender, pinnulate, and dichotomously branching portions of the arms of a crinoid; probably one of the fistulates. The objects along the middle of the figure are apparently the elements of the ventral sac. Schmidt's quarry, Davenport, W. H. Norton. (U. I. C. 3768.)

Fig. 9. *Megistocrinus clarkei* Thomas.

Part of the dome of a specimen on which the plates have been separated by crystalline expansion of the interior, about x2. Note the granular surfaces. Waterloo, Mrs. David Brant. (U. I. C. 3769.) See also Plate XL, figs. 1-8.

Figs. 10-11. *Megistocrinus fitzpatricki* Thomas.

10. Enlargement of a part of the base of a calyx to show the raised sutures and central nodes.

11. Enlarged view of a suture on same specimen showing the arrangement of the granules into ridgelets at right angles to the suture line. Type specimen. (Fitzpatrick Coll.) See also Plate XXXIX, figures 6, 7.

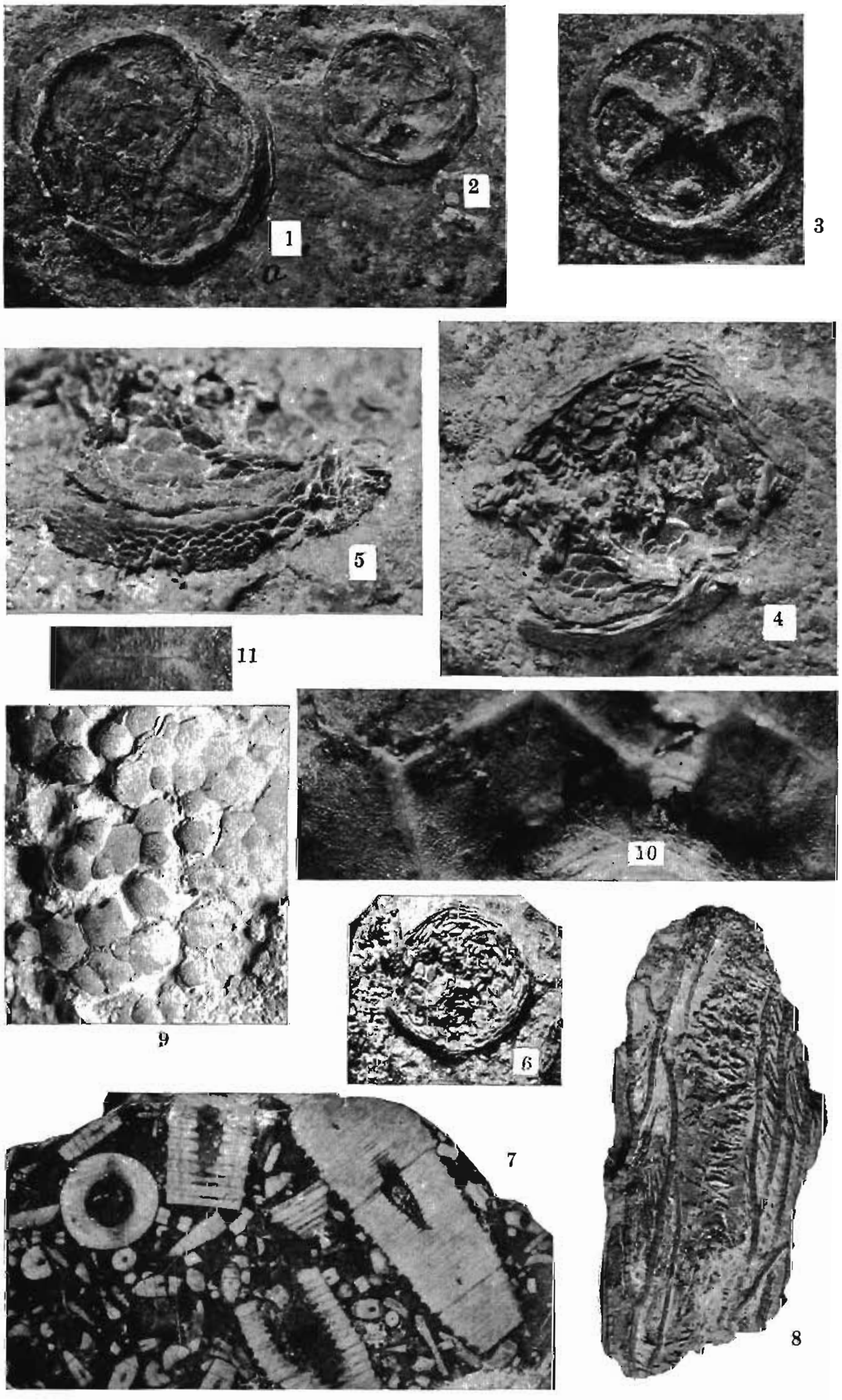
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PLATE XLVII.

Figs. 1-7. *Nortonechinus welleri* Thomas.

Fig. 1. The type specimen natural size. See enlargement, Fig. 7, also text figure 74. (U. I. C. No. 3044.) Rockford, C. H. Belanski.

Fig. 2. A part of the inner surface of the type specimen, x3.3. The brace, showing its lower surface, on the upper part of the figure is larger than any other found; its length is 11.5 mm. The object on the right side of the brace is thought to be the end of a compass. In the lower part of the figure is a half pyramid showing the retractor muscle depression; it is close to 12 mm. long. A chain of close-set ambulacral plates lies between the pyramid and the brace. They are seen from the inner side. Note the peculiar "hooks" which are a part of the imbrication, also the pore-pair.

Figs. 3-6. Four braces found loose among plates and spines, vicinity of Rockford. Figures are about x2; all are seen from the upper side. (They are U. I. C. Nos. 3047, 3048a, 3048b, and 3052a, respectively.)

Fig. 7. The type specimen about x3.3. A little of the right and left edges have been cut off in the illustration. Note the telescoping of the plates near the center of the specimen—due to accident in preservation—the spines clinging to the upper left hand corner, the diagonal arrangement of the plates, the vertical columns, the imbrication, the miliary spines, the scrobicular tubercles, and other features.

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PLATE XLVIII.

Nortonechinus welleri Thomas.

Plates and spines. All from the type localities west, northwest, and southwest of Rockford and a few from Hackberry Grove and vicinity. Collected by C. H. Belanski and A. O. Thomas.

Fig. 1. A row of typical spines seen from the side.

Fig. 2. Apical view of seven spines; the two on the left are round, the one on the right rounded polygonal.

Fig. 3. Basal view of seven specimens showing acetabulum.

Figs. 4-18. A lot of spines, x2. 4-7 show the stout shafts, the facets, and short bases, 8, 9 are acetabular views, 10 is a stout spine of unusual appearance, with a rudely circular termination, 11-16 illustrate the polygonal, somewhat radially pustulate, nearly flat apices of typical spines. Note that some are five- and that some are six-sided. 17, 18 are spines in which the apical face is oblique to the axis of the shaft. (Selected from a lot of 20, U. I. C. 3060.)

Figs. 19-20. Apical view of two spines nearly quadrangular in outline, x2. (U. I. C. 3061a, b.)

Fig. 21. A spine terminating in a spatulate, three-vaned apex, x2. (U. I. C. 3061c.)

Fig. 22. A spine with rounded polygonal apex, x2. (U. I. C. 3061d.)

Figs. 25-28. Apical views of four spines with circular or subcircular terminations, x2. Note the tendency toward a radial disposition of the ridglets and pustules; number 27 resembles the coronet-bearing apex of a *Xenocidaris* spine but has no central spinule and its shaft, figure 33, is much stouter. (U. I. C. 3062 a-d.)

Figs. 29-35. Lateral views of numbers 19, 20, 25-28, and 22, but slightly larger; 19 is same as 29, and so forth.

Fig. 36. A group of eighteen plates illustrating variety in outline and other features.

Figs. 37-49. A number of plates, x2. Number 39 is well above normal size; note that some of its sutures are curved toward the center; number 47 is of normal length but is only approximately one-third the normal width; numbers 48, 49 illustrate the adapical bevel of the inner surface bringing out the three areas modified, one for each plate concerned in the aboral imbrication. (U. I. C. 3095 a-m.)

Note.—The proportion of roundly terminated spines shown on this plate and the next compared to the number of polygonal spines shown is much greater than their relative abundance in the field.

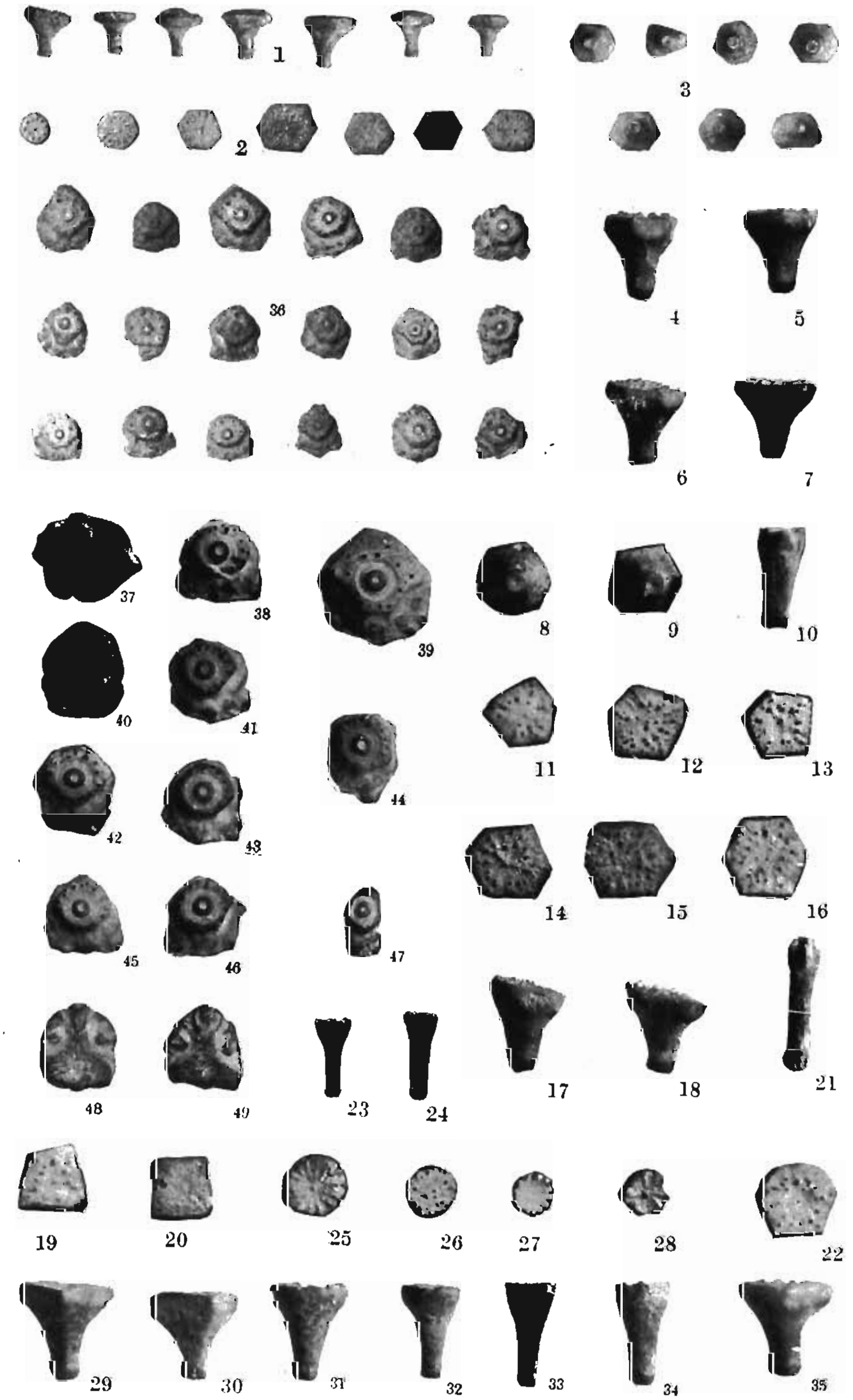


PLATE XLIX.

Figs. 1-6. *Nortonechinus welleri* Thomas.

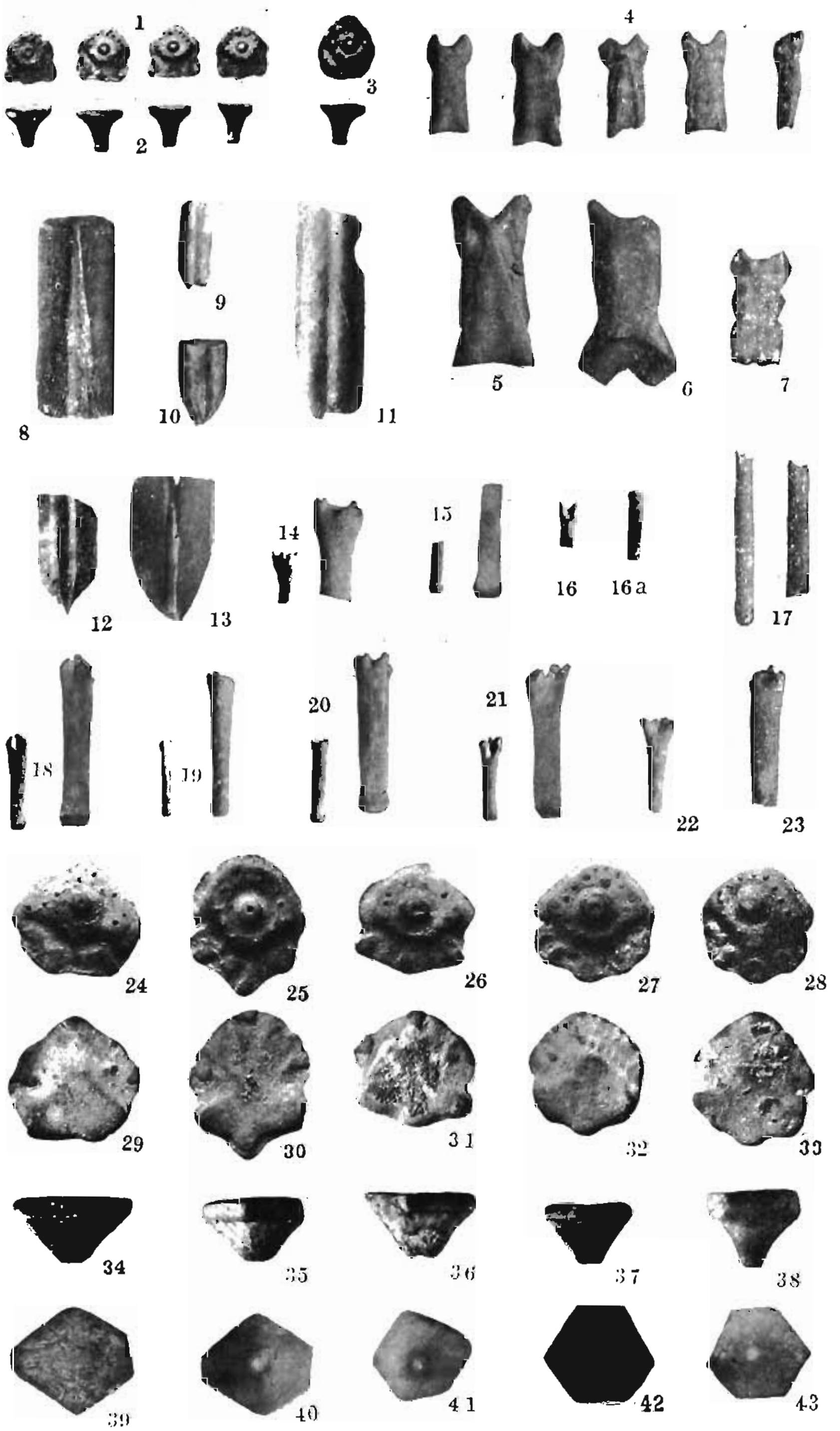
All collected by C. H. Belanski and A. O. Thomas in the vicinity of Rockford unless otherwise stated.

1, 2. Four interambulacral plates with well developed adoral flanges (U. I. C. 3054 a-d) and four typical primary spines. (U. I. C. 3055 a-d.) This is the lot of plates and spines whose measurements are given in the text. 3. An interambulacral plate and a primary spine. This pair is the basis of the drawings by Miss Horn, see text figure 78. Hackberry Grove, W. H. Norton. (U. I. C. 3056 a, b.) 4. An illustration of five braces, about x2; the two on the left are seen from above, the one on the right is seen from the side, the other two from below. The middle one is partly broken along calcite cleavage. (Left to right they are U. I. C. 3053a, 3048b, 3053b, 3048a, and 3053c.) 5. A nearly perfect brace seen from below, x3.3. (U. I. C. 3057.) 6. Brace seen from above, x3.3; same as third specimen of figure 4.

Fig. 7. Brace from the lantern of a modern sea urchin, *Dorocidaris papillata,* x3.3, introduced for comparison. Key West, 200 fathoms, S. U. I. Bahama Expedition. (U. I. C. 3058.)

Figs. 8-23. *Nortonechinus welleri* Thomas.

8. Part of tooth seen from within, showing the distal widening of the median groove, x3.6. (U. I. C. 3046a.) 9. A broken tooth, narrower than the last, face view, showing the ridges on either side of the median depression and the submarginal grooves, about x1.5. (U. I. C. 3045a.) 10. Tip of a tooth, face view, x2.3. (U. I. C. 3046c.) 11. Same as figure 9 but x3.8. 12. Tip of a tooth preserving the sharp point and the small lateral denticles, about x3.4. 13. Part of a tooth near the tip seen from within; same as figure 10 but x3.5. 14-23. A number of spines with very slightly expanded apices and which terminate in a number of prongs. 14. Two views of the apical portion of a spine, irregularly campanulate, ending in six spinules, x1 and x2. (U. I. C. 3052b.) 15. Proximal part showing base and part of shaft, x1 and x2. (U. I. C. 3052d.) 16. A bit of the apical part of a spine with very long prongs, one or two broken off. (U. I. C. 3052a.) 16a. A nearly cylin-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drical shaft ending in five blunt spinules. (U. I. C. 3052c.) 17. Two slender spines, each ending in three sharp points, x3.3. (U. I. C. 3059 a, b.) 18. A long stout spine, five-pronged, x1 and x2. (U. I. C. 3051a.) 19. A long and comparatively slender four-pronged spine, x1 and x2. (U. I. C. 3051d.) 20. A long stout example, five-pronged, x1 and x2. (U. I. C. 3051c.) 21. A seven-pronged spine, tips of prongs and the base lost, x1 and x2. (U. I. C. 3051b.) 22. An incomplete specimen with short spinules, x2. 23. Same as figure 16a, about x2.

Figs. 24-33. *Nortonechinus welleri latus* Thomas.

Outer and inner views of five typical interambulacral plates; figure 29 is inner view of 24, 30 of 25, and so forth, x2. West of Bird Hill in Cerro Gordo county, C. H. Belanski and A. O. Thomas. (U. I. C. 3049 a-e.)

Figs. 34-43. *Nortonechinus stainbrooki* Thomas.

Lateral, apical, and basal views of a number of the short squatty spines of this species, x2. Type specimens. Brandon, M. A. Stainbrook. U. I. C. 3093 a-f; figs. 34, 39, 40= 3093a; 35, 42, 43= 3093b; 41= 3093f; 37= 3093d; 38= 3093e; and 36= 3093c.) See also text figure 80.

PLATE L.

Figs. 1-25. *Xenocidaris americana* Thomas.

1. A left hemipyramid showing tooth slide, about x2. Rockford, C. H. Belanski (U. I. C. 3073.) 2. A complete and fairly typical spine, about x2 (U. I. C. 3074.) 3. A large but incomplete spine, about x2 (U. I. C. 3075.) 4. Apical expansion with prominent coronet and fluted sides, about x2 (U. I. C. 3076.) 5-8. Typical spines showing expansion and fluting, about x2 (U. I. C. 3077-3080.) 9-15. Apical views of a series to show the circular or subcircular coronets and the central pustule or pustules, about x2. Number 11 is same as number 6. (U. I. C. 3081-3086.) 16. Iamb plate, x2 (U. I. C. 3087.) 17, 18. Lateral view of spines showing fluting, about x2 (U. I. C. 3088, 3089.) 19, 20. Same as figures 4 and 3 but x2.3. 21-24. Apical views of specimens to show result of lateral compression, scarcely noticeable in first two, the third with two sides developed, the fourth nearly a complete polygon, about x2 (U. I. C. 3068-3071.) 25. A lot selected at random to show general features; one is nearly complete, from most of the others the slender part of the shaft is broken away (U. I. C. 3067.)

Figs. 26-35. *Nortonechinus* (?) *owenensis* Thomas.

26. Basal and apical parts of spines; also a hemipyramid, enlarged. 27. Same as figure 26, natural size. Near T. E. Wagner's home, C. H. Belanski (U. I. C. 3063, 3064 a-e, left to right.) 28, 29. A pair of worn and partly broken plates. Type locality, C. H. Belanski (U. I. C. 3065 a, b.) 30-35. A number of typical plates, x2. 30 shows typical *Nortonechinus* bevel; breakage and wear have obliterated most of the features. Type locality, C. H. Belanski (U. I. C. 3066 a-f.)

Fig. 36. *Devonocidaris jacksoni* Thomas.

Part of slab 3001, x4.5, to show parts of three teeth, also plates and spines. At end of the arrow near center of figure is a genital plate with the madreporite; see Pl. LI, figure 25. Bird Hill, A. O. Thomas.

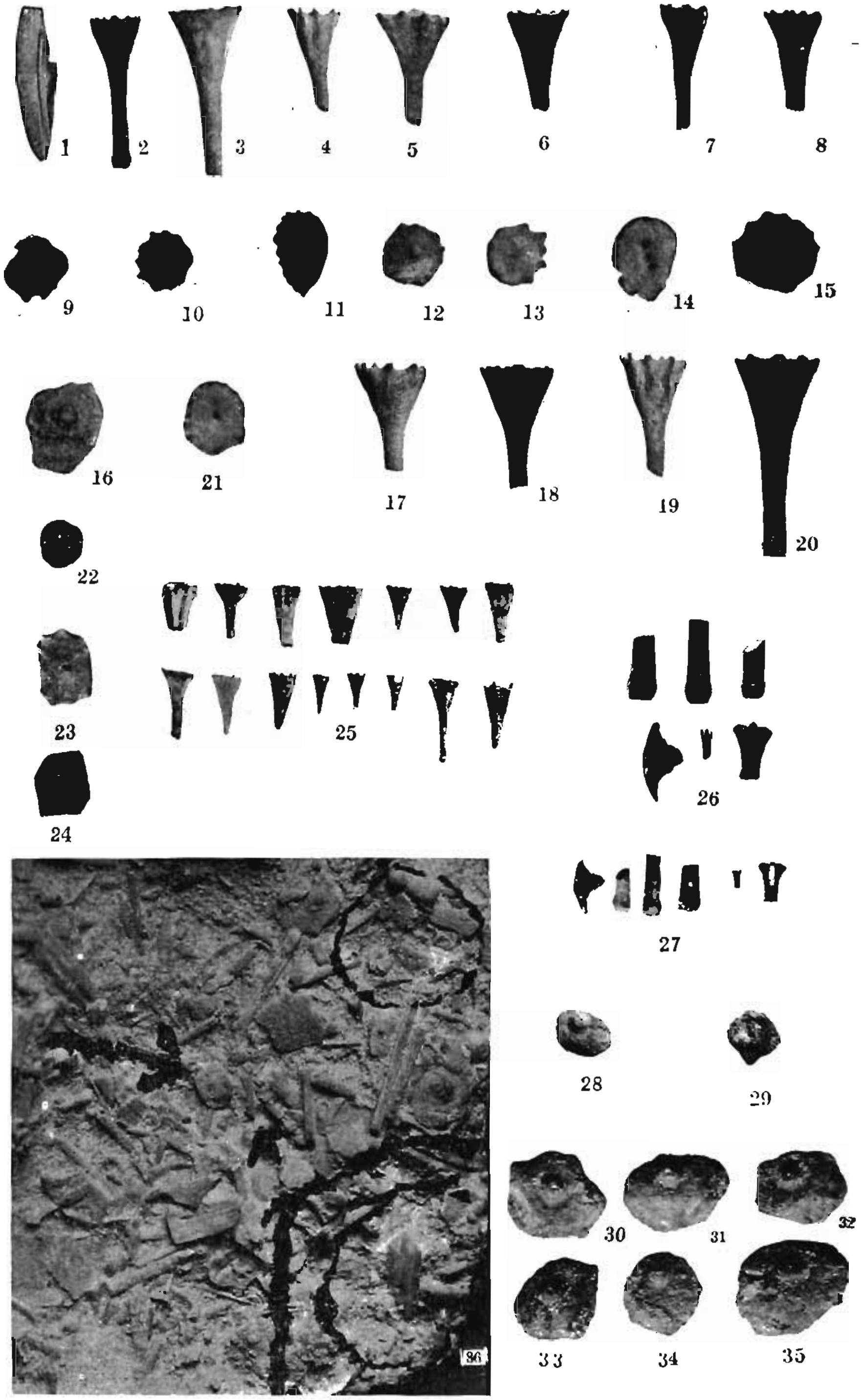
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PLATE LI.

Devonocidaris jacksoni Thomas.

Drawings by O. T. Walter, based on specimens from Bird Hill collected by A. O. Thomas.

Figs. 1-3. Side, face, and inner view of a half pyramid. Note the ridges for the attachment of the interpyramidal muscle, the retractor muscle scar, the rather deep foramen magnum, and the dental slide, about x6. (U. I. C. 3024.)

Fig. 4. Inner face of a half pyramid showing the triangular wing and tooth slide, about x6. See Plate LIII, fig. 2. (U. I. C. 3004.)

Fig. 5. Face view of a pyramid, restored and greatly enlarged; the foramen magnum should be wider.

Fig. 6. Similar to number 4, about x12; a part of the thin edge of the face next to the dental slide is broken away.

Figs. 7, 8. Two braces, x8.6. They are more slender than those of *Nortonechinus* (U. I. C. 3016.)

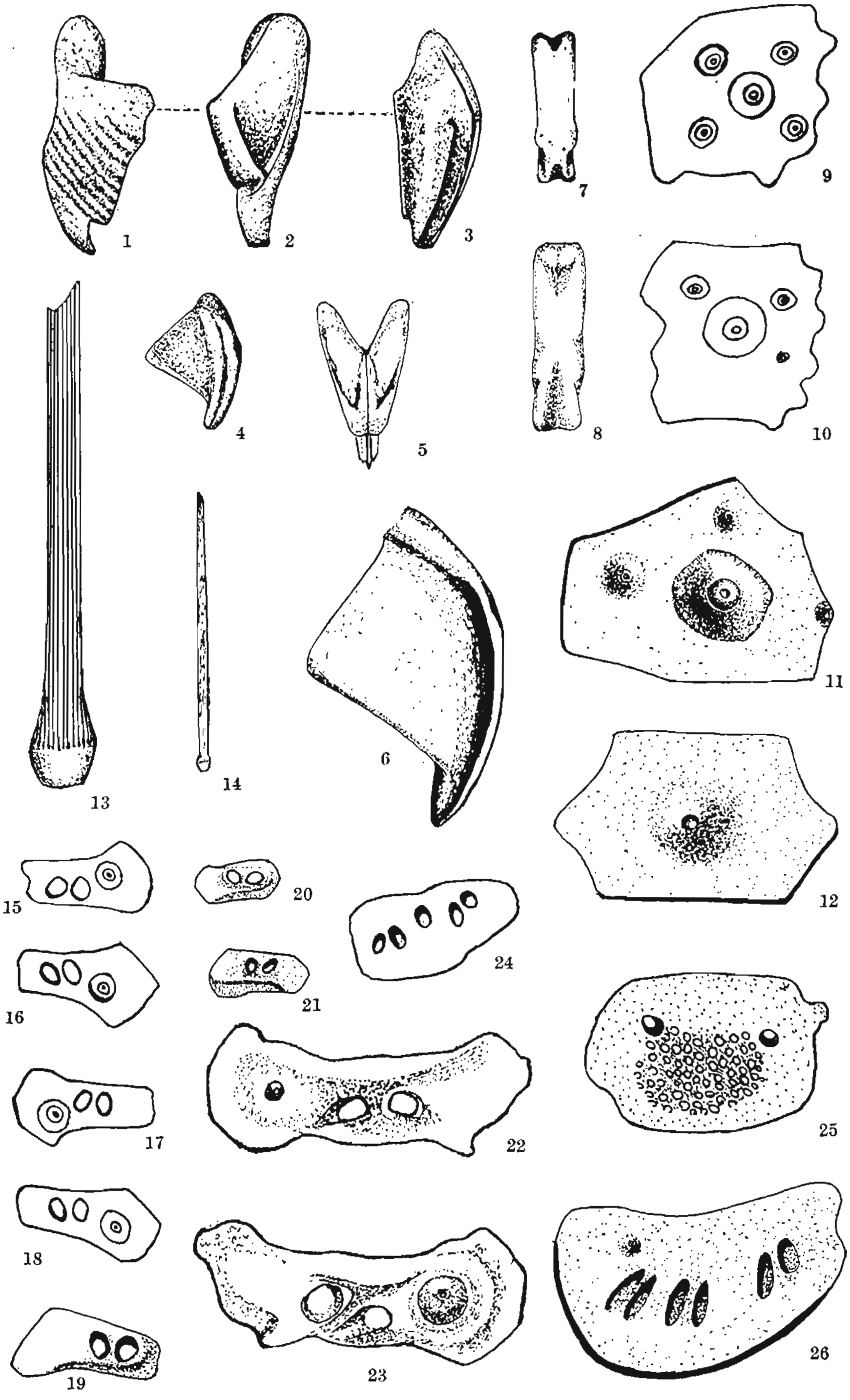
Figs. 9-12. Interambulacral plates, more or less broken; the first two x6, the last two x8.6. Note the distribution of primary and secondary tubercles, the parts of the primaries, and the terraced secondaries. The right borders of 9 and 10 are scalloped, they are thought to be adradials, their left margins are imperfect. Number 11 is much broken but shows well the low basal terrace. Number 12 is a nearly perfect hexagonal plate; it has little evidence of secondaries. See Plate LIV, figure 1. (Slabs 3012, 3005, 3010, and 3011 respectively.)

Fig. 13. A broken primary spine greatly enlarged. (After slab 3014.)

Fig. 14. Primary spine, about x2. (After slab 3008.)

Figs. 15-23. Ambulacral plates showing pore-pair, terraced tubercle, bevel, et cetera.

15. On slab 3013, x6.
16. On slab 3014, x6.
17. On slab 3013, x6.
18. On slab 3013, x6.
19. Inner surface; shows slight bevel, x7.7, on slab 3028.
20. A supposed demiplate with faint epipodium, x7.7, on slab 3001.
21. Another demiplate, x7.7.
22, 23. Ambulacral plates from screenings in the *De-*



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vonocidaris horizon. Greatly enlarged; may not belong to this species.

Fig. 24. A compound plate with five oval pores, about x20. (U. I. C. slab 3001.)

Fig. 25. Madrepore plate, about x17. See Plate L, fig. 36. (U. I. C. slab 3001.)

Fig. 26. A compound plate with elongate oval pores arranged in pairs, the three pairs forming a broad arc, x8.6. (U. I. C. slab 3010.)

PLATE LII.

Figs. 1-4. *Devonocidaris jacksoni* Thomas.
All from Bird Hill, A. O. Thomas.

1. Part of surface of slab x2.2, showing interambulacral plates, teeth, spines, and so forth. (U. I. C. 3020.)
2. Interambulacral plate showing primary tubercle and basal terrace, about x8. Same plate at lower center of figure 4. (U. I. C. 3020.)
3. Imperfect interambulacral plate showing faint basal terrace and a few scattered secondary tubercles, about x8.4 (U. I. C. 3006.)
4. Part of surface of same slab as figure 1, about x4.3. Note the jumble of plates and spines in upper left hand corner. About one-half inch to left of "4" is an ambulacral plate; there are three others near anterior margin of the brachiopod shell in the lower center.


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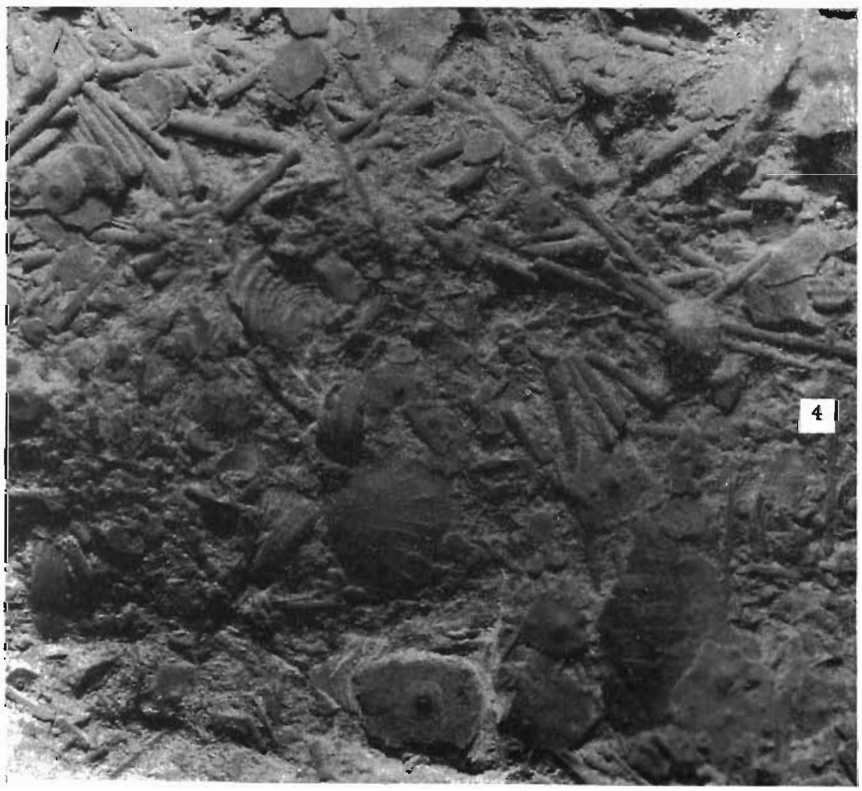
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PLATE LIII.

Figs. 1-7. *Devonocidaris jacksoni* Thomas.

All from Bird Hill, A. O. Thomas.

1. Part of maxilla showing oblique ridges on the interpyramidal face. About x4. (U. I. C. slab 3043.)
2. Inner face of right half-pyramid showing the prominent triangular lateral wing, the longitudinal curvature of the outer face, the tooth slide, and the pyramidal suture. About x2.5. (U. I. C. slab 3004.)
3. Part of surface of a slab showing the fine spines, outer face of a tooth, and small plates. About x2.3. (U. I. C. slab 3005.)
4. Interambulacral and a tuberculate ambulacral plate; note shape and position of the pore-pair. Note also the slender tooth near the right margin, x4.3. (Part of slab U. I. C. 3013.)
5. Interambulacral plate with faint basal terrace and two or three small secondary faintly terraced tubercles; also ambulacral plate seen from below. About x4.5. (U. I. C. slab 3011.)
6. Part of slab bearing various parts of test and lantern. Note the two left half-pyramids showing retractor muscle scars, angle of foramen magnum, and pyramidal suture; near tip of arrow in lower left hand part of figure is a compound plate with five perforations, the specimen is somewhat broken, x4.5. (U. I. C. slab 3039.)
7. Slab which is largely a conglomerate of the remains of this species. Note ambulacral plate with suggestion of a peripodium; also the maxillae, teeth, spines, etc., x4.5. (U. I. C. slab 3016.)

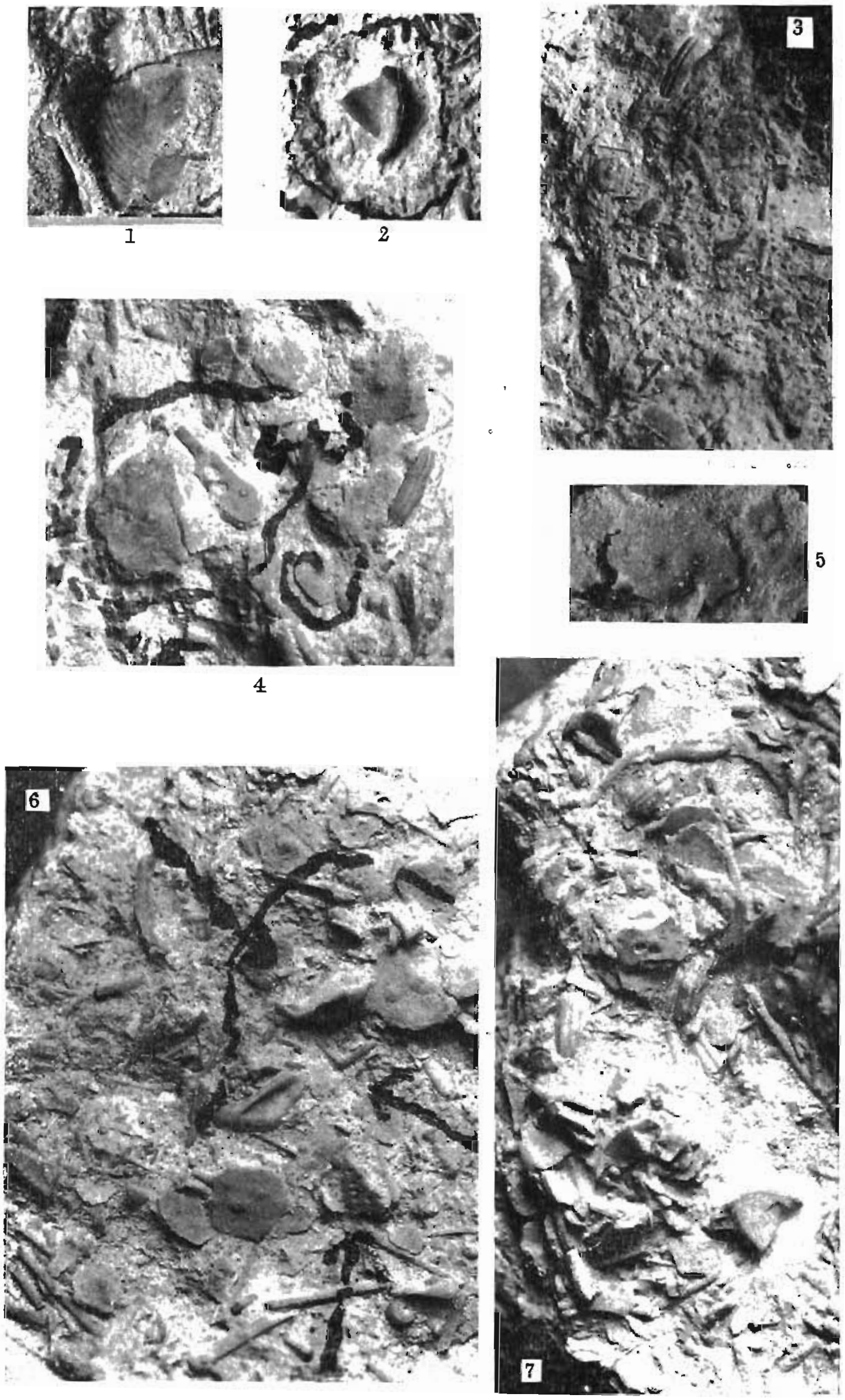
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PLATE LIV.

Figs. 1-6. *Devonocidaris jacksoni* Thomas.

All specimens from the Lime Creek shale at Bird Hill, collected by A. O. Thomas.

1. A hexagonal interambulacral plate with low primary tubercle and but little evidence of any secondaries, about x4. See Plate LI, fig. 12. (U. I. C. slab 3011.)
2. Interambulacral plate, probably an adradial; note the adhering miliary spines and secondary tubercles, about x2.5. (U. I. C. slab 3015.)
3. Maxilla, inner view showing tooth slide, x4.5. (U. I. C. slab 3040.)
4. Surface of a typical slab showing spines, plates, etc. At the tip of the arrow are three very slender spines, probably secondaries, about x4.5. (U. I. C. slab 3008.)
5. A slab crowded with spines, teeth, and plates. Note the markings on the inner face of the large tooth, also its point: median depression is well brought out on the face of the tooth above this. About x4.5. (U. I. C. slab 3020.)
6. Part of slab to show a long but incomplete primary spine. The specimen is 11.2 mm. long. Note also the ambulacral plate, x4.25. (U. I. C. slab 3014.)

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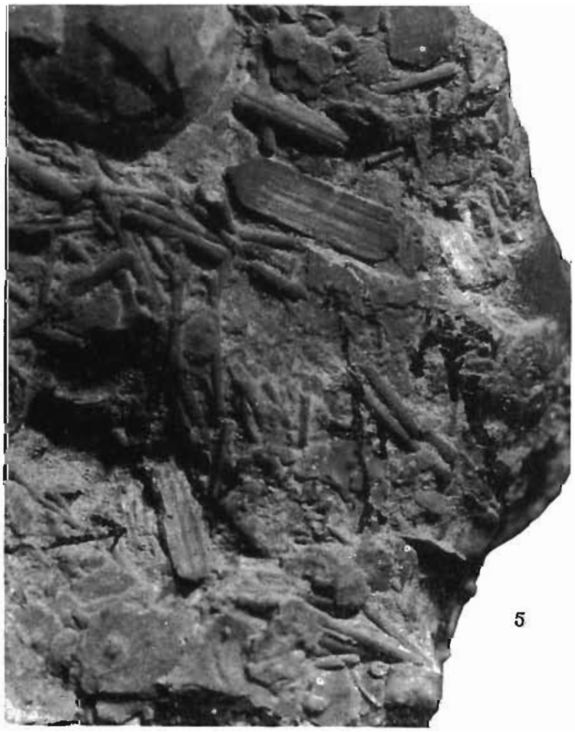

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