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Accompanying Papers

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FORTY-NINTH AND FIFTIETH ANNUAL REPORTS OF THE STATE GEOLOGIST

Iowa Geological Survey
Iowa City, Iowa
December 31, 1941

To Governor George A. Wilson and Members of the Geological Board:

Gentlemen:

The following report covering the calendar years 1940 and 1941 and four accompanying papers are submitted with the recommendation that they be published as Volume XXXVIII of the Annual Reports of the Iowa Geological Survey.

During these two years the program was carried forward much the same as formerly but with some changes in the emphasis. In general, the policy is to give increasing attention to those studies and services that permit practical, direct and prompt return to the tax-paying public of the State in the form of information, advice and help in the development of water supplies and other domestic and industrial raw materials.

At this date the great war in Europe, Asia and Africa has been in progress for more than two years and American participation in a world war for twenty-five days. With the inauguration of selective service in the autumn of 1940 and the development of war industries, new and increased demands appeared for geological information and guidance both in the preparedness and direct war programs and for the expansion of war industries. These demands will doubtless grow in frequency and urgency as the war progresses and for its duration.

More specifically the various activities are as follows:

Well Water Supplies

Studies and services connected with the production of underground water through wells continue to constitute the largest and most important single part of the program. In 1941 more than sixty percent of the funds, personnel and program were devoted to geological work on the development of well water supplies for domestic, industrial, and war uses. Information, advice and direct help are given as new wells are considered, planned for, located, drilled, and used. Such service to cities, towns, state parks, peace-time industries, and individuals is being continued. Recently similar service has been extended to problems of development of much larger supplies of well water for training camps, munitions plants, air bases and expanded food and war materials producing industries.

The geological aspects of this work are done or directed by Dr. H. G. Hershey, Assistant State Geologist. He is assisted by K. E. Anderson, Junior Geologist, D. A. Davis and J. B. Carrier, geological assistants, and several part-time student assistants. Unfortunately the mineral analysis of well water from different geological sources has had to be abandoned, temporarily it is hoped, because of lack of funds and personnel, both of which were formerly supplied from the Work Projects Administration.

By a continuation and expansion of cooperative agreements with the Ground Water Division of the Water Resources Branch of the U. S. Geological Survey under Mr. T. W. Robinson, Engineer, assisted by A. P. Gerardi, Junior Engineer, the study of water pumpages, levels and reserves has made considerable progress. At the end of 1941 there were 262 observation wells in operation. It is probable that some of the Iowa underground reserves are being overpumped and depleted. As this program gets older and data accumulate the development of new and increased water supplies can be accomplished more intelligently than has been possible previously.

Several of the states have enacted legislation designed to place the planning, locating, drilling, and abandoning of wells under State regulation. The Geological Survey together with the Department of Health, the Conservation Commission, the Iowa Water Well Drillers Association, and some of the consulting engineers of the Iowa Engineering Society, and with the advice and criticism of ground-water experts of the U. S. Geological Survey has given considerable attention to such legislation for this State. The idea is to improve the well water supplies, to avoid waste, and to reduce unnecessary costs.

Stream and Lake Gaging

Cooperation with the Surface Water Division of the Water Resources Branch of the United States Geological Survey in a stream and lake gaging program has been continued. The main purpose is to secure, record, and supply data on low flow, flood flow and average annual flow of Iowa streams and of low, high and average stages in the more important Iowa lakes. There is an increasing demand for these data from those engaged in projects of flood control, soil erosion prevention, navigation, recreation, power development, water supply, stream pollution, fish and game, silting, weather statistics, designing bridges, culverts, dams, etc.

Since early in 1940 when R. G. Kasel was called to Washington to take charge of stream gaging in all of the states, the Iowa program has been directed by L. C. Crawford, District Engineer of the U. S. Geological Survey. He is assisted by a number of engineers of varying Civil Service rating and a few non-Civil Service men. At present 71 stream gaging stations are in operation and 10 lake stations. This represents an increase of 7 stream stations since the last report on December 31, 1939. The mass of information concerning the surface water supplies of the State is coming to be respectable in quantity and quality. Its value and usefulness depend largely on the length of time during which records are kept and on continuity of recording. Now that a good start has been made on keeping continuous records, the program should be continued without interruption by all means and it should be expanded if possible.

Oil and Gas

Since the last report two years ago a considerable amount of geological and geophysical exploratory work on oil and gas has been done by major and minor oil companies and seven tests have been drilled. All but one reached their objectives and were abandoned as dry holes. One other is still drilling on this date. Unfortunately so far no oil or gas in commercial quantities has been discovered.

All of these tests were made in southwestern Iowa in the northern portion of the Forest City Basin where geological conditions are considered to be more favorable than elsewhere in the State. One test was made in Union County, three in Taylor County, one in Fremont County, and two in Montgomery County.

The operators of these drillings complied in all respects with the law (48th G. A., Senate File 328) and welcomed the cooperation of the Geological Survey far beyond the legal requirements. Once locations were announced along with the notification of intention to drill, state geologists forecast the depths at which possible producing formations would be reached, agreed with operators and drillers concerning the taking of drilling samples, watched much of the drilling directly, made laboratory studies of the samples, kept running geological logs, and gave advice concerning casing seats, sampling and shutting off of waters from different depths, testing different formations for oil, and final abandonment and plugging. All information so gained was of course held in strict confidence until release by the operator.

It is probable that the test now drilling will be completed and that other tests will be made at other locations. It is still too early to determine that Iowa either will or will not eventually produce oil or gas in commercial quantities.

Coal Bearing Beds

Work on the rock formations with which Iowa coal beds are associated which was started in 1932 is nearing completion or at least the point of diminishing returns. Papers by Professor A. C. Tester of the University and D. S. Stookey formerly a graduate student at the Unversity and by Professor L. M. Cline of the State College and D. S. Stookey, it is hoped, will be finished and submitted within the next few months. The results of this work include clearer and better ideas of how these beds and the associated coals were deposited originally and what changes they have undergone since their deposition, more knowledge of the thickness and persistence of the coal beds and correlations of the Iowa strata with similar beds in Missouri on the south and Illinois on the east.

Dr. H. L. Olin, Professor of Chemical Engineering at the University, has continued his studies of the properties of Iowa coals and has completed a manuscript on "The Preparation of Stoker Coals from Iowa Screenings" which will be published soon as University of Iowa Studies in Engineering, Bulletin 28.

It is believed that the Iowa coal industry is in position to meet any demands for increased production that may be brought about by the promotion of the war, provided legislation is not unfavorable.

Pleistocene Geology

Dean George F. Kay assisted by Jack B. Graham, a graduate student in the University has completed Part II of an exhaustive work on the glacial or Pleistocene Geology of Iowa. This paper published in this volume will be of practical use in the mapping, interpretation and use of soils, in the prevention of soil erosion, in the never-ending search for sand and gravel deposits, and in the study of and service on shallow wells that supply water from glacial or interglacial materials.

Shales and Clays

Professor C. S. Gwynne has completed several years of work on the shales and clays of the State and his paper entitled "Ceramic Shales and Clays of Iowa" appears farther along in this volume. This paper should be of interest and value to operators of brick and tile and cement plants.

In cooperation with the State College departments of geology under Professor John T. Lonsdale and ceramic engineering under Professor C. M. Dodd, investigations were started to determine the properties of and if possible to find uses for the underclays that occur beneath most of the Iowa coal beds. The time of Mr. G. D. Monk was contributed by the Department of Geology at Ames and his field work was supervised by Professor L. M. Cline; the Geological Survey paid the field expenses; and tests of underclays collected by him are being carried out under the direction of Professor Dodd. At this time the work is incomplete.

Agricultural Lime Surveys

Only one additional county has been surveyed for agricultural lime since the last report. At the request of the Agricultural Adjustment Administration Soil Conservation Association in Lee County a special survey of the agricultural lime resources was undertaken. At the expense of the Geological Survey the field work was done by Clifford Adams. Invaluable help was given by Delbert T. Foster, County Agricultural Agent who gave office space in the Court House for Mr. Adams and handled the samples, and by members of the County Soil Conservation Committee who aided in locating exposures in the field. The samples were analyzed for carbonate content under the direction of Professor B. J. Firkins of the Department of Agronomy at the State College. A report was prepared and made available to interested parties in Lee County.

The amount of agricultural lime that could be used to advantage on Iowa land is almost unlimited. The amount and purity of limestone available, the thickness and character of overburden, the cost of crushing and the distance and cost of transportation from quarry source to land to be limed are all factors.

The location, sampling and determination of overburden can best be done by geologists. The Geological Survey should probably give more service along this line in the future.

Mineral Production

Figures on mineral production are being collected as usual in cooperation with the U. S. Bureau of Mines. "Mineral Production in Iowa in 1939 and 1940" by H. G. Hershey is published in this volume.

Other Activities

No further progress has been made during the last two years with the preparation of county reports. Audubon, Floyd, Greene, and Union Counties have been surveyed but the reports and maps await checking and revision, and Calhoun and Shelby Counties still remain to be surveyed. Otherwise the 99 counties have been surveyed and the reports have been published.

Study of the "Cambrian Strata of Northeastern Iowa" by Walter C. Schuldt has been completed and the results are published under this title and authorship in this volume.

Past attempts to locate raw material for the manufacture of rock wool and to encourage manufacturers to locate plants in Iowa have not been successful to date. The one existing plant in Iowa secures its raw material from outside the State. A large plant which it was hoped would be located in Iowa finally went to Minnesota where it is located near an important market.

Respectfully submitted,
Arthur C. Trowbridge
Director and State Geologist

THE ILLINOIAN AND POST-ILLINOIAN PLEISTOCENE GEOLOGY OF IOWA

by

GEORGE F. KAY AND JACK B. GRAHAM

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Dr. George F. Kay died on July 19, 1943. It is greatly to be regretted that he did not live to see this product of his labors in final print. The first proofs had been revised by him and although the final proofs have been read entirely by others, no changes have been made aside from the correction of obvious errors.

THE ILLINOIAN AND POST-ILLINOIAN PLEISTOCENE GEOLOGY OF IOWA

BY GEORGE F. KAY AND JACK B. GRAHAM

Abstract

This report makes available in one place the present day evidence and interpretations of the Illinoian and Wisconsin glacial stages, and the Sangamon and Recent interglacial stages of the Pleistocene geology of Iowa.

Four chapters deal with the following subjects:

Chapter I	The Centralian epoch (series): The Illinoian glacial age (stage)
Chapter II	The Centralian epoch (series): The Sangamon interglacial age (stage)
Chapter III	The Eldoran epoch (series): The Wisconsin glacial age (stage)
Chapter IV	The Eldoran epoch (series): The Recent interglacial age (stage)

In chapter I the distribution, origin, and characteristics of the Illinoian drift are discussed; typical sections of the drift are given, and each of the Illinoian drift phases is described in detail, namely, the gumbotil, the oxidized and leached drift, the oxidized and unleached drift, and the unoxidized and unleached drift. Evidence is given for the judgment that the Illinoian drift is on the average about 30 feet thick.

In chapter II interglacial features of Sangamon age are discussed, such as sands and gravels, late Sangamon loess, peat deposits and soils, and Lake Calvin—its origin and history. Sangamon erosion and the record of life of the age are described.

The Loveland formation receives somewhat detailed treatment. The history of the formation is outlined, sections of Loveland loess and sands and gravels are given, and the results of detailed laboratory studies, involving mechanical and mineral analyses, are presented and their significance indicated. Reference is made to volcanic ash in the formation.

Chapter III includes a discussion of the Iowan glacial subage (substage), the Peorian intraglacial subage (substage), and the Mankato glacial subage (substage).

The Iowan glacial subage (substage) deals with the distribution, origin, and changes in the Iowan drift. Sections of Iowan drift in northeastern and in northwestern Iowa are given. Iowan boulders, the Iowan pebble band, the oxidized and leached Iowan till, and the Iowan gravels—upland gravels and terrace gravels—are described.

The Peorian intraglacial subage (substage) describes in considerable detail the Peorian loess, its distribution and topographic expression, also typical sections. Mechanical, mineral, and chemical analyses, the vertebrate and invertebrate life and other characteristics, including the depth of leaching and thickness of the loess throughout the State, are presented.

A comparison is made between the Peorian loess and the Loveland loess, the former of which is related in age and, in part, in origin to the Iowan glacial substage; the latter was deposited sometime within the Loveland interval, which includes the time between late Yarmouth age and immediately pre-Iowan age.

The Mankato glacial subage (substage) is described in relation to the distribution of the drift, its origin, and the changes which the drift has undergone. Typical sections of the drift are given and the drift phases are dis-

cussed in considerable detail. The Mankato gravels—upland gravels and terrace gravels—are described. The thickness of the Mankato drift is discussed.

In chapter IV the record of the Recent subage (substage), the chief features of the Recent and its probable duration are discussed.

Many figures and maps accompany the report.

This report is intended as a complementary report to the "Pre-Illinoian Pleistocene Geology of Iowa" published by Kay and Apfel more than ten years ago. The two reports will constitute "The Pleistocene Geology of Iowa."

INTRODUCTION

In the year 1928, "The Pre-Illinoian Pleistocene Geology of Iowa" was published by Kay and Apfel in Volume XXXIV of the reports of the Iowa Geological Survey. Exclusive of the Preface, Introduction, and Concluding Statements, this report contained the following chapters:

Chapter I	The bedrock surface of Iowa
Chapter II	Topography and drainage of Iowa
Chapter III	History of the investigations and classifications of the Pleistocene geology of Iowa
Chapter IV	The Nebraskan glacial stage
Chapter V	The Aftonian interglacial stage
Chapter VI	The Kansan glacial stage
Chapter VII	The Yarmouth interglacial stage

When this pre-Illinoian part of the Pleistocene geology of Iowa was prepared, it was the hope of the senior author that at some later time an equally comprehensive report might be prepared on that part of the Pleistocene of Iowa not discussed in detail in the pre-Illinoian report. Such a report has now been completed and is being presented for publication. It is entitled "The Illinoian and Post-Illinoian Pleistocene Geology of Iowa." In the preparation of this report there has been no hesitation about using many facts which have appeared in former papers dealing with the Pleistocene of the state. The report will make available in one place the present day evidence and interpretations of the Illinoian and Wisconsin glacial stages and the Sangamon and Recent interglacial stages of the Pleistocene of Iowa.

When the report on the pre-Illinoian Pleistocene geology of Iowa was published, it seemed wise to set aside 500 unbound copies with the purpose in mind that after the Illinoian and post-Illinoian Pleistocene geology report had been published, the two reports, 500 copies of each report, should be bound together and designated "The Pleistocene Geology of Iowa." Part I would be "The Pre-Illinoian Pleistocene Geology of Iowa" and part II, "The Illinoian and Post-Illinoian Pleistocene Geology of Iowa." This plan will be followed. It is intended also to include in this "Pleistocene Geology of Iowa" a bibliography of the Pleistocene of Iowa and adjacent states of the Mississippi Valley.

Since the publication of the pre-Illinoian report, some significant papers have been published by the senior author. Chief among these are the following:

Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 425-466, 1931.
Origin of the pebble band on Iowan till: Jour. Geology, vol. 39, no. 4, May-June 1931.
(With M. M. Leighton) The Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-673, 1933.
Pleistocene history and early man in America: Geol. Soc. America Bull., vol. 50, pp. 453-464, 1939.

The classifications of the Pleistocene of the Mississippi Valley and of Iowa are recognized by the Iowa Geological Survey as follows:

Classification of Pleistocene geology in the Mississippi Valley

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

Classification of the Pleistocene geology of Iowa

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

The chapters of the report on the Illinoian and the post-Illinoian Pleistocene geology of Iowa are as follows:

Chapter I	The Centralian epoch (series): The Illinoian glacial age (stage)
Chapter II	The Centralian epoch (series): The Sangamon interglacial age (stage)
Chapter III	The Eldoran epoch (series): The Wisconsin glacial age (stage)
Chapter IV	The Eldoran epoch (series): The Recent interglacial age (stage)

The authors wish to acknowledge their obligation to the late Dr. James H. Lees, Assistant State Geologist of Iowa from 1906 until 1934; also to express their thanks to Dr. E. T. Apfel, Dr. Paul T. Miller, Dr. Neil A. Miner, Dr. R. W. Edmund, and Dr. Cornelia C. Cameron. Results of their studies have been drawn upon freely and used in various ways in this report.

CHAPTER I

THE CENTRALIAN EPOCH (SERIES) THE ILLINOIAN GLACIAL AGE (STAGE)

Discrimination of the Illinoian drift
Distribution of the Illinoian drift in Iowa
Origin of the drift
Changes in the drift
Typical sections of the Illinoian drift
Descriptions of the drift phases
  The Illinoian gumbotil
  Oxidized and leached Illinoian till
  Oxidized and unleached Illinoian till
  Unoxidized and unleached Illinoian till
Thickness of the Illinoian drift

The Centralian epoch (series)[1] includes the Illinoian glacial age (stage) and the Sangamon interglacial age (stage). The Illinoian glacial age followed the Yarmouth interglacial age and is the third of the glacial ages in the Pleistocene period. The glacial drift of the Illinoian age was first distinguished by Leverett.[2] It was described by him in 1899 in his monograph on the Illinois glacial lobe and was named from the State of Illinois, where he had made his most extensive studies of the drift sheet. It was first named the Illinois glacial lobe, but the name has been changed by later usage to Illinoian to agree with the names of other stages. The Illinoian was the last drift sheet to be differentiated in the Mississippi Valley although the Nebraskan drift did not receive its present name until ten years later, in 1909, when Shimek[3] gave that name to the drift sheet that had previously gone by the nondescript names of Sub-Aftonian and Pre-Kansan. The glacial map of Iowa, figure 1, shows the drift sheets and other glacial features of the state.

The Illinoian ice sheet came into Iowa from the Labradorean center. The drift left by this ice sheet is exposed widely in Illinois, Indiana, and Ohio.

DISCRIMINATION OF THE ILLINOIAN DRIFT

For the most part the Illinoian drift is similar to the older drifts on which it lies. It is typically a dark-gray clay with unassorted pebbles of varied kinds and sizes. Boulders are present, but large ones are uncommon. However, one granite erratic was observed

[1] Kay, G. F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 448-452, 1931.
[2] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, 1899.
[3] Shimek, Bohumil, Aftonian sand and gravels in western Iowa: Geol. Soc. America Bull., vol. 20, pp. 399-408, 1909.

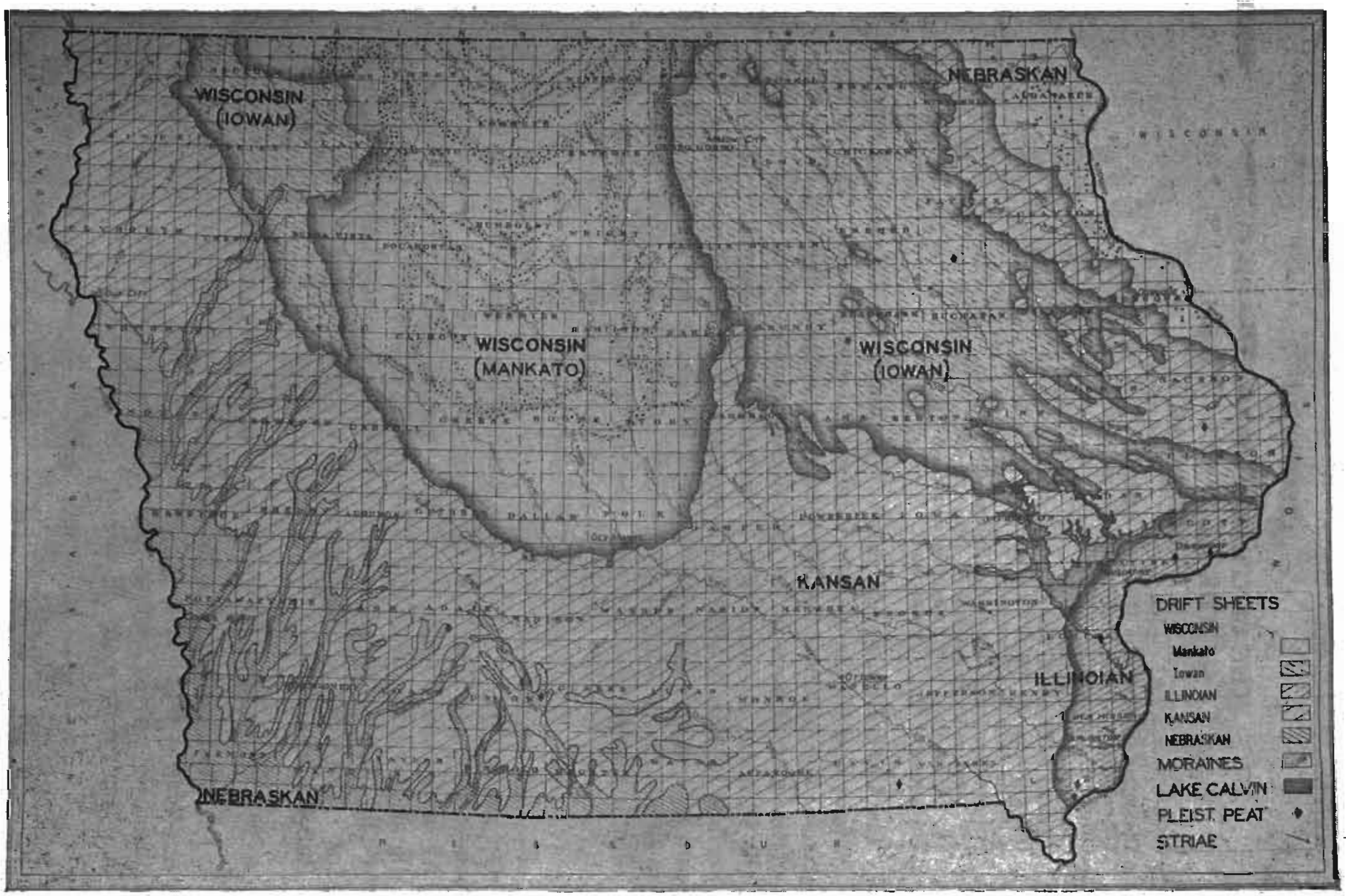

Figure 1. Map showing the surface distribution of the drift sheets and other glacial featuresof Iowa.

the dimensions of which above ground were 24 by 21 by 10 feet. In places the Illinoian till seems to be rather lighter in color than are the typical Kansan and Nebraskan tills, and at other places it is quite sandy. This sandy feature, however, is shared by all the drift sheets. Like the other drift sheets also, this one includes great pockets or lenses of gravels that either are surrounded by till or lie on its surface. The best known example of these gravels is in the valley of Mad Creek in the northeastern outskirts of Muscatine. That the Illinoian drift sheet has passed through essentially the same succession of events as had the older sheets before it is indicated by the presence over its upper surface of gumbotil as much like the Kansan and Nebraskan gumbotils as those tills are like the Illinoian till. This difference is to be noted, however, that whereas the Nebraskan and Kansan gumbotils average above 8 and about 11 feet in thickness respectively, the average maximum thickness of the Illinoian gumbotil is less than 5 feet. It is evident that conditions favorable for gumbotil formation were not so long continued after the uncovering of the Illinoian drift sheet as after the formation of the older ones. Such gravels as lay at or near the surface of the drift were strongly leached until their soluble constituents were removed entirely from the upper parts.

Normally, the Illinoian drift rests on Kansan gumbotil or, where this was eroded before the oncoming of the Illinoian glacier, on Kansan till in various stages of oxidation and leaching or on Kansan gravels. Kansan drift caps the Nebraskan drift everywhere within the area in Iowa covered by the Illinoian drift sheet, and it is not known that the Kansan was anywhere entirely eroded from above the Nebraskan, allowing the Illinoian drift to rest directly on Nebraskan.

Above the Illinoian materials may be found late Sangamon or Loveland loess, soil or peat, Peorian loess and wind-blown sand. Perhaps Iowan drift overlies Illinoian in the area of their contact, but this has not been seen on account of the thickness of the loess and sand in this region. The loess and sand materials have been seen on Illinoian gumbotil and on both the leached and unleached phases of the oxidized till.

Because the different drift sheets resemble each other in general composition and character, it is difficult to distinguish them when similar phases are found in contact. If unleached Illinoian till lies directly on unleached Kansan till the two might not be distinguishable. It is much more common, however, to find yellow oxidized

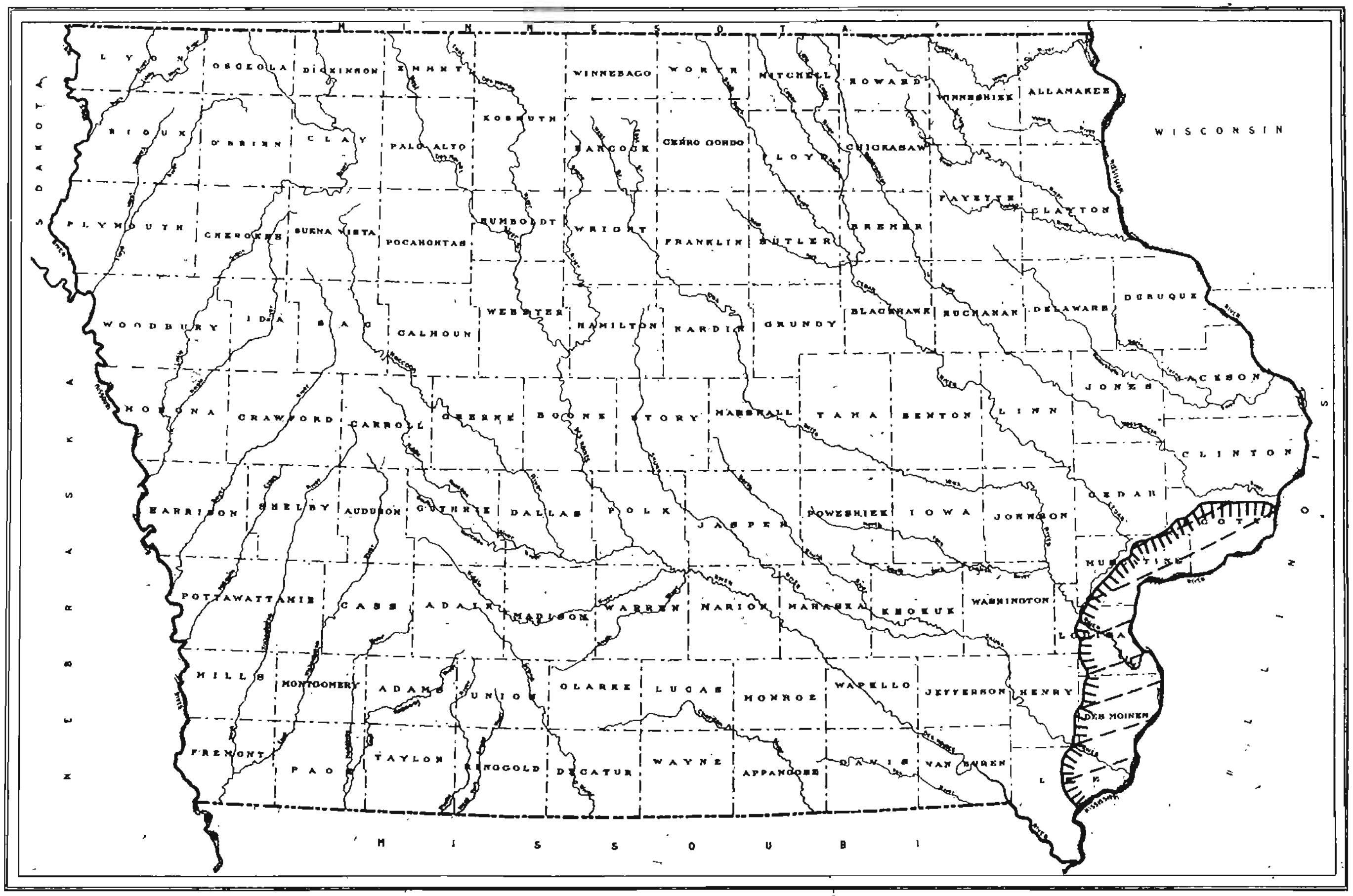

Figure 2. Map of Iowa showing the extent of Illinoian glaciation in the state.

till, either leached or unleached, on Kansan gumbotil. In this case the upper till may be called Illinoian with assurance; and where any other unlike phases lie in contact, their ages may be known with equal certainty.

DISTRIBUTION OF THE ILLINOIAN DRIFT IN IOWA

The Illinoian glacier was near its maximum extent when it reached the Mississippi River on its long journey from the Labradorean center of dispersion. Therefore, it pushed over into Iowa for only a few miles; and the sheet of drift that it left has a width west of the Mississippi ranging from about 4 miles at Muscatine to about 20 miles a short distance north of Burlington. The northern limit of the drift is probably somewhere near the mouth of the Wapsipinicon River and its southern extremity in Iowa is just south of Fort Madison. Some parts of the margin grade indefinably into the Kansan drift plain; elsewhere, as at West Point, a distinct moraine marks the boundary between the two plains; and between Stockton, Moscow, and Columbus Junction, a low area, the site of glacial Lake Calvin, follows the edge of the Illinoian glacial lobe, figure 2.

The Illinoian ground moraine must have been level, for the gumbotil plain that was developed on it, like that on the Kansan ground moraine, stretched out smoothly for miles. The two main drainage lines that cross it, Iowa and Skunk Rivers, have wide valleys that are incised far below the plain, and in general a dendritic drainage system is fairly well developed. Nevertheless, wide areas of the gumbotil plain still remain, modified only by the deposition over them of several feet of loess. This loess bears decisive evidence of being of two ages, because in places a lower body of compact leached loess is overlain by unleached loess that grades up into leached loess. The lower loess is late Sangamon or Loveland in age; that is, post-Illinoian gumbotil, while the upper loess is the Peorian loess of Iowan age and post-Iowan age. While the Loveland loess is not universally present in the Illinoian area, its exposures are so generally distributed that there is warrant in assuming that its original extent over the Illinoian drift was comparable to that of the Peorian loess in early Wisconsin time.

When the Illinoian glacier crossed the Mississippi Valley, it filled this valley with ice and glacial debris and forced the river to find a new course around the advancing front of the ice sheet. This stream course must have continually changed with the altering ice front, but when the ice finally came to rest, the waters of the river were ponded by the high lands near Columbus Junction and eventually formed a lake that covered the present lower course of Cedar River and extended far up the Cedar and Iowa valleys. This body of water has been named Lake Calvin, and its history has been traced in detail by Schoewe[4] and outlined in a later part of this report.

ORIGIN OF THE DRIFT

The Illinoian drift undoubtedly was derived in very large measure from the older drift sheets over which it passed. These were the Nebraskan and the Kansan; but to what extent the Illinoian glacier found each of these drift sheets at the surface is, of course, undetermined, as comparatively little is known of the distribution of these drifts in the states east of Iowa. Because the two earlier glaciers came from west of Hudson Bay while the Illinoian came from the Labrador peninsula, the course of the later glacier would be nearly at right angles to that of the earlier ones, and it is quite possible that boulders and other material that originated in the Keewatin region and that lodged in the states south of the Great Lakes may have been moved westward later by the Illinoian ice as far as western Illinois or Iowa.

The erosive work of the Illinoian glacier would naturally be, in the first place, to remove any interglacial materials that had accumulated on the older drift sheets or in valleys cut into them. Next would come the cutting away of the gumbotils, then of the oxidized and leached tills, the oxidized and unleached tills, and, if erosion proceeded far enough, the upper parts of the unoxidized and unleached tills. With such a body of leached materials to be scraped off, it seems remarkable that the Illinoian drift, as it was finally constituted, should have contained much calcareous matter. The fact, however, that any section of Illinoian drift that exposes a thickness of 10 feet or more does show unleached material is evidence that the Illinoian ice did plow deeply into the unleached till and probably, locally at least, into the bedrock beneath.

The Illinoian drift sheet, then, comprises unsorted and unstratified bodies of clay and coarser material; in other words, typical glacial till; and also masses of sand and gravel that were more or less assorted and laid down as bedded deposits.

[4]Schoewe, Walter H., The origin and history of extinct Lake Calvin: Iowa Geol. Survey, vol. 29, pp. 49-222, 1920.

CHANGES IN THE DRIFT

As soon as the Illinoian drift, both till and gravel, was uncovered, it became subject to the action of weathering and other physical and chemical agencies. Rains and their consequent surface and subsurface waters began to dissolve and reassort and otherwise modify the materials of the drift. Plants and animals would alter the texture and composition of the till, and the gases of the atmosphere and those produced by chemical reactions would aid in this work of change. It was not long until oxidation of the iron content and perhaps of other components as well altered the color of the upper part of the drift from its original gray to a yellowish tinge. Accompanying this oxidation, although much slower, was the leaching of the lime carbonate and probably other readily soluble elements and the carrying away of these materials in the ground water. The single unleached and unoxidized zone of the original, fresh, unaltered drift sheet would thus soon be divided into two zones, the upper of which was oxidized although still unleached, and as alteration progressed downward, a third zone would be introduced, the uppermost leached zone. But alteration has not stopped at this stage, and the leached matter has been still further modified; the clay constituents have been broken down into simpler compounds, some of which have been carried out; the sands, gravels, and even the boulders removed until at present the upper few feet of the till contains practically no boulders and only a few pebbles, these being of the most nearly insoluble types only. This residual material is the Illinoian gumbotil and it seems to have covered practically all the Illinoian drift plain. Illinoian gumbotil is exceptionally widespread in Illinois. Detailed studies in that state have resulted in the recognition of zones equivalent to the gumbotil, but which reflect different types of drainage sufficiently to merit separate recognition. Thus, typical, flat upland areas with poor drainage result in gumbotil. Well-drained areas result in a silty, comparatively open-textured material termed silttil. An intermediate condition of drainage results in a product which is intermediate in texture (between gumbotil and silttil), known as mesotil.[5]

It seems remarkable that the thoroughly leached material that lies beneath the gumbotil and that grades upward into it should have a thickness of not over 3 feet in most places. This seems to indicate that leaching progresses very slowly under the protective

[5]Leighton, M. M., and MacClintock, Paul, Weathered zones of the drift-sheets of Illinois: Jour. Geology, vol. 38, pp. 38-45, 1930.

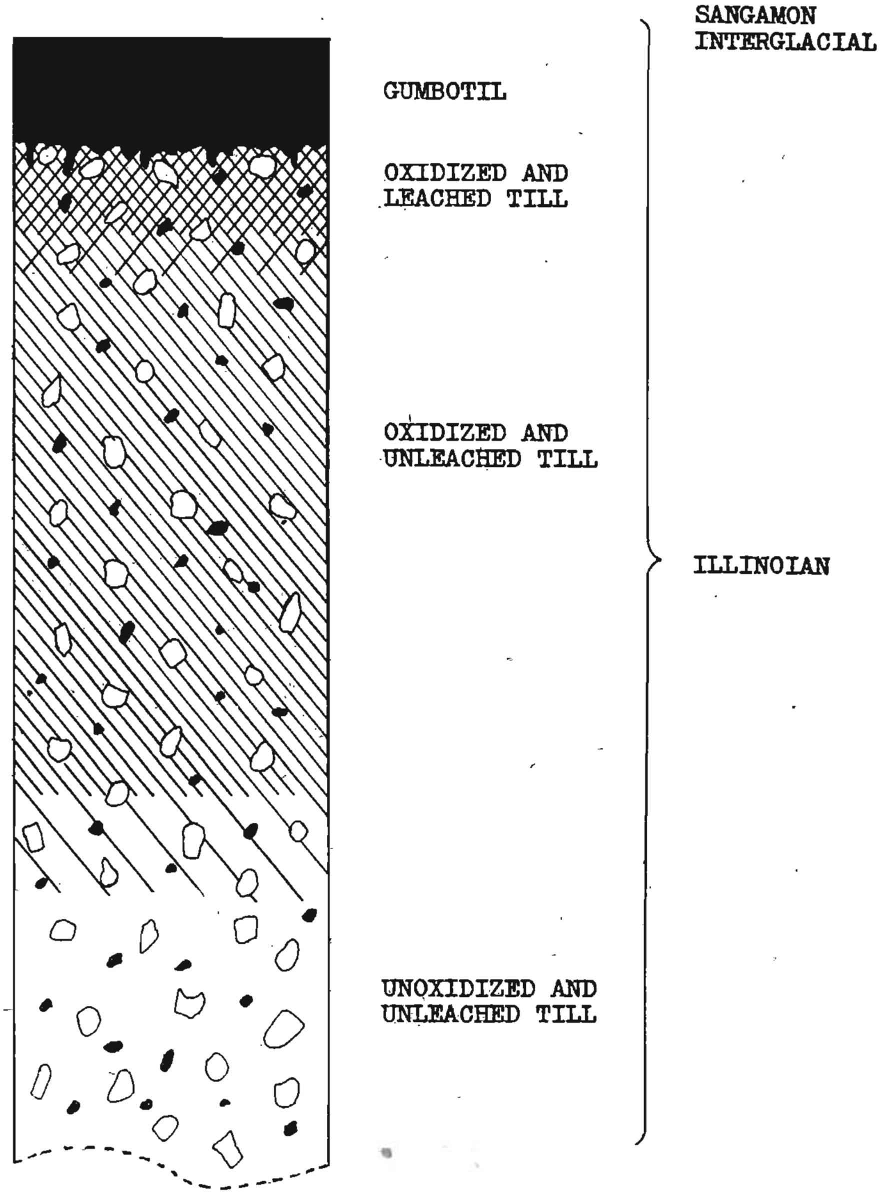

Figure 3. Diagram of a complete normal section of Illinoian till.

cover of the gumbotil. Complete sections of the Illinoian may be seen today in which the till is oxidized to a depth of 30 feet, but in which leaching has advanced only 2 to 7 feet below the gumbotil.

However, weathering does not stop with the development of gumbotil; in places this layer is still further changed until the sticky, compact, gummy clay is robbed of some of the constituents that give it this character, and it becomes a mealy, almost loam-like clay. Figure 3 is a diagrammatic representation of a typical section of Illinoian till showing the succession of changes which are found in Iowa. This sequence of till phases is also known as the soil profile, and the profile of weathering.

In Illinois, much work has been done on these zones of weathering. The various horizons have been numbered and are equivalent to the geologic terminology of the till phases as used in Iowa, as shown in the following table:

	Soil profile horizon number[6]
Gumbotil	Horizon 1 (surficial soil)
	Horizon 2
Oxidized and leached phase	Horizon 3
Oxidized and unleached phase	Horizon 4
Unoxidized and unleached phase	Horizon 5

In the case of gravels lying near the surface similar alteration may be expected to take place. Oxidation and leaching would progress much as in till until the soluble pebbles would be removed. It seems probable that further weathering of igneous materials might even form a residuum similar to gumbotil. Such material has been given the name gumbosand.[7]

[6]Leighton, M. M., and MacClintock, Paul, *op. cit.*, p. 32.
[7]Leighton, M. M., and MacClintock, Paul, *op. cit.*, p. 41.

TYPICAL SECTIONS OF THE ILLINOIAN DRIFT

Exposures in Scott County

One of the most complete sections of the Illinoian till and of the associated overlying and underlying materials is exposed in the southwest environs of Davenport, in the SE¼ sec. 30, Rockingham Township, (T. 78 N., R. 3 E.), Scott County. State highway 22 descends the Mississippi valley wall through a ravine and joins U. S. highway 61 near the foot of the bluff. About one-half mile west of the junction the following section may be studied on the north side of the road as one descends from the Illinoian upland:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, lower part gray; rises 28 feet to upland. Exposed here	8	
Sangamon interglacial stage:		
Loess, Loveland, brown, leached, some secondary calcium carbonate	1	6
Illinoian glacial stage:		
Gumbotil, gray typical	3	
Till, oxidized and leached	3	
Till, oxidized and unleached, only a few feet exposed here, but shown a little farther down the road to total of	30	
Yarmouth interglacial stage: Weathering and erosion of underlying deposits.		
Kansan glacial stage:		
Gumbotil, typical	5	
Till, oxidized and leached	5	
(Below this zone the till is shown down to the unoxidized phase).		

The upland here lies about 760 feet above sea level; therefore, the elevation of the Illinoian gumbotil is about 730 feet, and that of the Kansan, about 695.

A number of road cuts and other exposures in Scott County show interesting phases of the Illinoian and post-Illinoian materials. Near the Wapsipinicon River the Peorian loess is thin and the till shows through in numerous places. But 3 or 4 miles from the river the loess thickens to 10 or 15 feet or more and no till is seen. Probably this is within the Illinoian area. In the vicinity of Eldridge, the Illinoian plain is quite markedly level. Here the loess is 12 to 15 feet thick and overlies gumbotil which averages about 3 to 4 feet in thickness. A road grading just west of the corners of secs. 8, 9, 16, and 17, Lincoln Township, (T. 79 N., R. 4 E.), is interesting as showing the leaching of loess on the level Illinoian plain. It exposes the following:

	Feet	Inches
Peorian intraglacial substage:		
Humus		6
Loam		6
Loess, yellow to light brown, compact, leached	4	
Loess, unleached, has concretions. Exposed	1	

About 1½ miles southeast from this exposure, in the NW¼ sec. 22, Lincoln Township, (T. 79 N., R. 4 E.), the topopraphy shows a relief of about 30 feet, all of which appears to be in loess. Here is an outcrop of two loesses, the upper one, Peorian, being buff and leached in its upper part, gray and calcareous below, with iron tubules. The basal part of the exposure shows 3 to 4 feet of Loveland loess in irregular contact with the Peorian. The upper foot of the Loveland is dark with carbonaceous matter while the lower 3 feet is brown. It is all leached although it contains some lime concretions that were precipitated from the calcareous loess above.

Another section near the one just described carries the sequence somewhat further down the series. It is on a hillside near the NE¼ sec. 27, Le Claire Township, (T. 79 N., R. 5 E.), on the road leading down to Le Claire. Along the roadside Illinoian gumbotil is exposed more than 40 feet below the upland, and over it is loess, apparently all Peorian. Oxidized and unleached Illinoian till outcrops about 10 feet below the gumbotil.

Several sections in Davenport show some phases of the series of events that are not everywhere to be seen. One of these is just south of the high school building between Harrison and Main Streets. When studied it showed:

	Feet
Peorian intraglacial substage:	
Loess, buff colored, unleached	15
Sangamon interglacial stage:	
Loess, Loveland, purplish, leached	4
Illinoian glacial stage:	
Till, reddish, oxidized, leached, the result of leaching of the colloids from the Illinoian gumbotil; therefore, secondary profile	3
(This member shows a long lapse of time between the development of the gumbotil and the formation of the late Sangamon loess).	
Till, oxidized, unleached, many concretions. Lower part unoxidized and unleached. Exposed	10

Exposures in Muscatine County

A cut along State highway 22, in the middle of the E½ sec. 36, Fulton Township, (T. 78 N., R. 1 E.), Muscatine County, where the road turns northwest, about a mile northwest of Blue Grass, shows in an interesting way the relation of the Illinoian to the Kansan till.[8] The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess and soil	1	6
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Till, leached almost to a gumbotil at top, lower part oxidized but calcareous	7	
Yarmouth interglacial stage: Weathering and erosion of underlying deposits.		
Kansan glacial stage:		
Soil band, in places plowed by the Illinoian ice and drift		6
Gumbotil, surface irregular and showing plowing in places; drab to gray; contains siliceous and other pebbles, also concretions in lower part	11	
Till, oxidized and leached. Visible in roadside ditch.		

The Kansan gumbotil is about 715 feet above sea level and the upland lies 50 feet higher than this, at least 40 feet of this being in loess. A similar exposure of gumbotil overlain by Illinoian till occurs about one-half mile northwest of this one on the north line of sec. 36.

A large body of gravels of Illinoian age is exposed in a small branch of Mad Creek in the southwest corner of sec. 23 and the southeast corner of sec. 22, Bloomington Township, (T. 77 N., R. 2 W.). These gravels are evidently pockets in the till and because they rise nearly to the upland level, they show weathering features similar to those produced in the drift. The gravels are highly oxidized and reddened and cemented by iron oxide in the upper part; but, for the most part, are light grayish-buff in color. The gravels are leached for 7 feet. Oxidation has advanced 12 feet below the upland level and the fact that the overlying loess, 15 feet in thickness, is leached for only about 5 feet demonstrates that the leaching of the gravels is pre-Peorian. Elsewhere the gravels of this mass seem to have been eroded in connection with the cutting out of Mad Creek Valley, and less leaching is shown here than maximum Sangamon leaching, which has been found to be about 12 feet.

Exposures in Louisa County

In the SE¼ sec. 26, Grandview Township, (T. 75 N., R. 3 W.), Louisa County, a gully has worked back from a small tributary of the Mississippi River and has exposed a fine section of the Illinoian

[8]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, p. 266, 1929.

drift about 200 yards east of the diagonal road. The surface in the vicinity is level upland and the whole association must give a picture of conditions about as they have persisted since Peorian time. The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, upper part buff, leached, lower part gray, calcareous, iron tubules. To upland	10-12	
Sangamon interglacial stage:		
Soil band, dark gray to black, highly carbonaceous	1	6
Illinoian glacial stage:		
Gumbotil, dark gray to drab on dry surface, sticky, tenacious, leached, few pebbles. Grades into the soil band above	3	6
Till, oxidized and leached	2	
Till, oxidized and unleached; lighter yellow than the phase above. Exposed on slope to bottom of gulch	20	

This is one of the clearest sections of the Illinoian to be found within its area. The gumbotil is about 650 feet above sea level and, in its relation with the soil band, illustrates the very gentle slope of the original gumbotil plain.

On the north bluff of Iowa River Valley, in the center of the SW¼ sec. 4, Grandview Township, (T. 74 N., R. 3 W.), is an interesting exposure. The uppermost material is loess and wind-blown sand, both of which were derived, doubtless, from the river bottoms near-by. The gumbotil is carbonaceous in its upper part and is very dark, almost black in color, and very sticky. It is here about 2½ feet thick although a nearby section shows 5 feet of gumbotil. The lower part of the gumbotil contains sand pockets and some lime concretions. It lies about 20 feet below the upland.

Exposures in Des Moines and Henry Counties

The Illinoian gumbotil upland, overlain by loess, is wonderfully developed in Des Moines County. U. S. highways 61 from Burlington north through Mediapolis and 34 from Burlington west and northwest through New London stretch across this plain and give very typical views of a topography that must have endured with but slight change since the Illinoian glacier melted back from this area many thousands of years ago. Because of this level character and slight erosion, deep exposures of the drift are uncommon. However, a number of shallow cuts show that the same materials are present here as elsewhere in the area covered by the Illinoian ice. The abandoned brickyard at Mediapolis still shows beneath about 2 feet of dark soil a Peorian loess that is light gray mottled with brown. The lower half is somewhat lighter than the upper half, but the whole body, 6 feet in thickness, is noncalcareous showing that leaching here has progressed 8 feet from the surface since the beginning of Peorian deposition. Under this loess is Loveland loess exposed to water level 3 feet, leached, drab, evidently much older than the upper loess (fig. 4).

South of Latty and east of the railroad station, in sec. 29, Benton Township, (T. 71 N., R. 2 W.), is a section as follows:

Figure 4. Exposure showing dark soil, Peorian loess, and Loveland loess. Brick and Tile plant, Mediapolis, Des Moines County.

	Feet	Inches
Peorian intraglacial substage:		
Loess	5	6
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil, drab, typical	3	6
Till, oxidized and leached	2	6
Till, oxidized and unleached. Several feet exposed.		

Latty is just below the upland; consequently, this section reveals a condition almost unmodified since Illinoian time except by weathering and by deposition of Peorian loess.

Kay and Apfel[9] described a fine section of Illinoian drift over Kansan drift just south of New London. It is on the south slope of a small creek valley and is along the road leading toward Lowell, in the NE¼ sec. 34, New London Township, (T. 71 N., R. 5 W.). The record is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, leached. To upland	8	
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil, leached, with upper part gumbotil-like but with much of the colloidal material carried out. Chocolate colored in upper 4 feet, less reddish below	5	
Till, oxidized and leached	2	
Till, oxidized but unleached, looking very much like the Kansan till. Measured along the slope	40	
Yarmouth interglacial stage: Weathering and erosion of underlying deposits.		
Kansan glacial stage:		
Gumbotil, drab, tough, leached but some lime concretions, few pebbles	11	
Till, oxidized and leached	5	
Till, oxidized and unleached. Seen to creek bed	12	

This shows one of the thickest sections of Illinoian till seen in this state. The gumbotil and leached till are both of normal thickness for the Illinoian drift.

Exposures in Lee County

Only the eastern quarter of Lee County was covered by Illinoian ice, but within this area are now exposed some very clear sections of glacial materials. A ravine in the west part of sec. 20, Denmark Township, (T. 69 N., R. 4 W.), has been cut through unleached but oxidized Illinoian till that is about 20 feet thick. It lies on Kansan gumbotil that is dark above and gray below. In places at the gumbotil level are to be seen gravel masses that have been leached and reddened during the processes that changed the till to gumbotil.

An exposure that shows the thinnest section of Illinoian till so far seen is in a gulch that is cutting back from Mississippi River in the SW¼NE¼ sec. 35, Washington Township, (T. 68 N., R. 4 W.), on the south side of U. S. highway 61. The section is:

[9]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, p. 228, 1929.

	Feet	Inches
Peorian intraglacial substage:		
Loess-like clay, grayish to yellowish, leached	7	
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil, gray to drab, some concretions, some chocolate color in mottling. Few pebbles	4	
Till, oxidized, leached, some patches of gray gumbotil-like material; in places has many pebbles	2	
Yarmouth interglacial stage: Weathering and erosion of underlying deposits.		
Kansan glacial stage:		
Gumbotil, gray to drab, concretions	5	
Till, oxidized and leached	7	
Till, oxidized and unleached	8	
Till, unoxidized and unleached. Basal contact not seen.		

Near the southeast corner of sec. 33, Washington Township, (T. 68 N., R. 4 W.), close to the city limits of Fort Madison, is a gully that is cutting into the edge of the upland that here reaches to the valley of the Mississippi River. This gully has exposed an exceptionally good section of the Illinoian. One remarkable feature of the topography here is that as the observer stands at the head of this ravine, he may look across the city to the river and the Illinois bluffs beyond; and yet the water in this ravine flows away from the river to a small tributary that eventually does empty into the Mississippi. The section exposed is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, grayish yellow to buff yellow, leached	7	
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil, drab to chocolate brown or dark color, starch-like fracture, few pebbles, leached; grades into underlying till	4	6
Till, oxidized and leached	6	
Till, oxidized and unleached. To base of gulch	15	

Several sections east of West Point show a normal succession of thin Illinoian over Kansan. One of these is along the roadside between the SW¼ sec. 34, Pleasant Ridge Township, (T. 69 N., R. 5 W.), and the NW¼ sec. 3, West Point Township, (T. 68 N., R. 5 W.). From the road corner westward this shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess-like clay, about	8	
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil, about	3	
Till, oxidized, unleached in lower part; contains much chert	11	

	Feet	Inches
Yarmouth interglacial stage:		
Soil zone, loess-like, light gray above, black below, with carbonaceous streaks		10
Gumbotil, exposed	10	

This section is only about 2 miles from the margin of the Illinoian.

A series of natural exposures along the ravine followed by the Batavia branch of the Chicago, Burlington and Quincy Railroad in the southwest part of sec. 28, Washington Township, (T. 68 N., R. 4 W.), affords one of the best Pleistocene sections in the state. These have been described by Kay and Apfel[10] and need be only summarized here. The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	3	
Sangamon interglacial stage: Weathering and erosion of underlying deposits.		
Illinoian glacial stage:		
Gumbotil	4	6
Till, oxidized and leached	5	6
Till, oxidized and unleached	1	
Yarmouth interglacial stage: Weathering and erosion of underlying deposits.		
Kansan glacial stage:		
Gumbotil	8	6
Till, oxidized and leached	5	
Till, oxidized and unleached, as shown along the ravine	37	
Aftonian interglacial stage:		
Peat, with sticks and logs as much as 6 inches in diameter	3	
Silts and sands, leached, at same level as the peat, but about 100 yards downstream. A few feet.		
Nebraskan glacial stage:		
Till, black to gray, unleached. Elevation about 600 feet.		

This section begins just back of a farmhouse on State highway 103 at the bend in the southwest corner of sec. 28 and extends for half a mile down the valley along the railroad. The different elements have differing thicknesses in their various outcrops, but the above shows the general succession.

DESCRIPTIONS OF THE DRIFT PHASES

The Illinoian Gumbotil

The Illinoian gumbotil is the most distinctive phase of the Illinoian drift. As in the formation of the Nebraskan and Kansan gumbotils, weathering under favorable conditions has produced a zone which contrasts sharply in color and texture with other Illinoian drift phases. The color of the gumbotil is essentially drab

[10]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, pp. 149-151, 226-227, 1929.

gray when dry, as in the two older gumbotils. On a fresh surface the gray is slightly mottled with brown. When wet, the gumbotil is dark, with color variations in the zone becoming more distinct. In many cases, the jointed and fractured polyhedral blocks, at or near the surface, are stained with the yellowish brown colors of an iron oxide coating.

The textural character of the Illinoian gumbotil is a second prominent feature by which it may be distinguished readily from other drift phases. Upon drying, the gumbotil tends to joint and fracture due to shrinking volume and the widening of these cracks produces the typical minute polyhedral blocks which are characteristic of gumbotil. The joints are irregular in extension and face, but are so well developed that fracture of the material is uncommon, separation in most cases being along the joints. The blocks produced by separation along these joints are polyhedral with wedge shapes predominating, from 1 to 5 or 6 millimeters in dimension. A secondary set of joints spaced a centimeter or more apart shows slickensided surfaces in some cases. Root tubules are few, for most of the roots follow the joint lines.

The mass texture, or the relation of the constituent blocks of the mass to one another, is best described as "starch-like" in fracture. This habit is the most readily discernible in gumbotil wet enough to be molded by the hands. In this respect, the Illinoian gumbotil is more like the Kansan gumbotil than the Nebraskan, which does not display the remarkable jointing to so high a degree. The Illinoian gumbotil, as is true of the older gumbotils, exhibits a "hackly appearance" on a dry surface in which the polyhedral blocks are so minutely cracked as to present a crumbly appearance yet retaining a surprising mass coherence.

The clastic texture, or the character and disposition of the unit rock or mineral particles making up the till deposits, is more evidence of the individuality of gumbotil among the drift phases. The Illinoian gumbotil studied has a general similarity which can be observed in the field, but is much more evident from laboratory studies. The mechanical analyses of the gumbotils from six different locations (fig. 5) show a maximum percentage of material in the silt and clay grades below 1/64 millimeter in diameter. In four of the six analyses, more than 65 percent of the material is finer than 1/64 millimeter in diameter while in one sample there is as low as 39 percent within this size grade. In five of the analyses, the general decrease in the percentages of each grade varies with

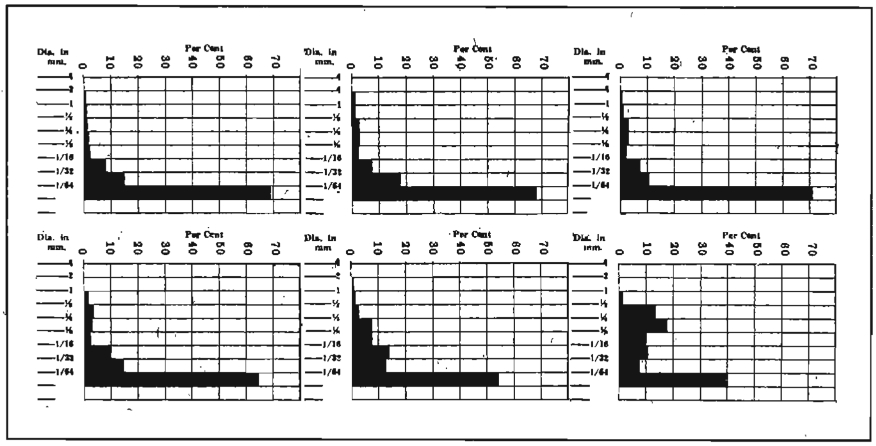

Figure 5. Graphs showing mechanical analyses of Illinoian gumbotil from six different localities.

the incrêase in the size grades, The other analysis is distinctly different showing a low percentage of material in the size grade below 1/64 millimeter in diameter and more than 30 percent of the sample between 1/8 and 1/2 millimeter which is explained by the sandy texture of the till.

These analyses show that in general the clastic textures of the gumbotils are similar, but at the same time there are variations in the clastic textures of the gumbotils just as found in normal ungumboized till. Not only are there likenesses within the Illinoian gumbotils, but a comparison of an average of the Illinoian gumbotils with the Nebraskan and Kansan gumbotils (fig. 6) shows that the analyses of all of the gumbotils, although of different ages, are so much alike that it would be impossible to differentiate the different ages of gumbotil on the basis of clastic texture.

The lithologic content of the Illinoian gumbotil is of the same character as that of the Nebraskan and Kansan gumbotils. The lithologic analyses of gumbotils below show a high percentage of siliceous pebbles which is in agreement with the interpretation that gumbotil is a residual weathered product of till:

	Nebraskan Gumbotil	Kansan Gumbotil	Illinoian Gumbotil	Average of Gumbotils
Quartz	36.75	48.50	45.00	43.25
Chert	21.75	31.80	46.00	32.92
Quartzite	20.25	7.40	0.09	9.25
Granite	8.25	7.80	2.40	6.15
Basalt and Greenstone	11.25	2.90	3.30	5.82
Feldspar	1.25	1.00		.75
Sandstone		0.50	2.30	0.93
Felsite	0.50		0.10	0.20

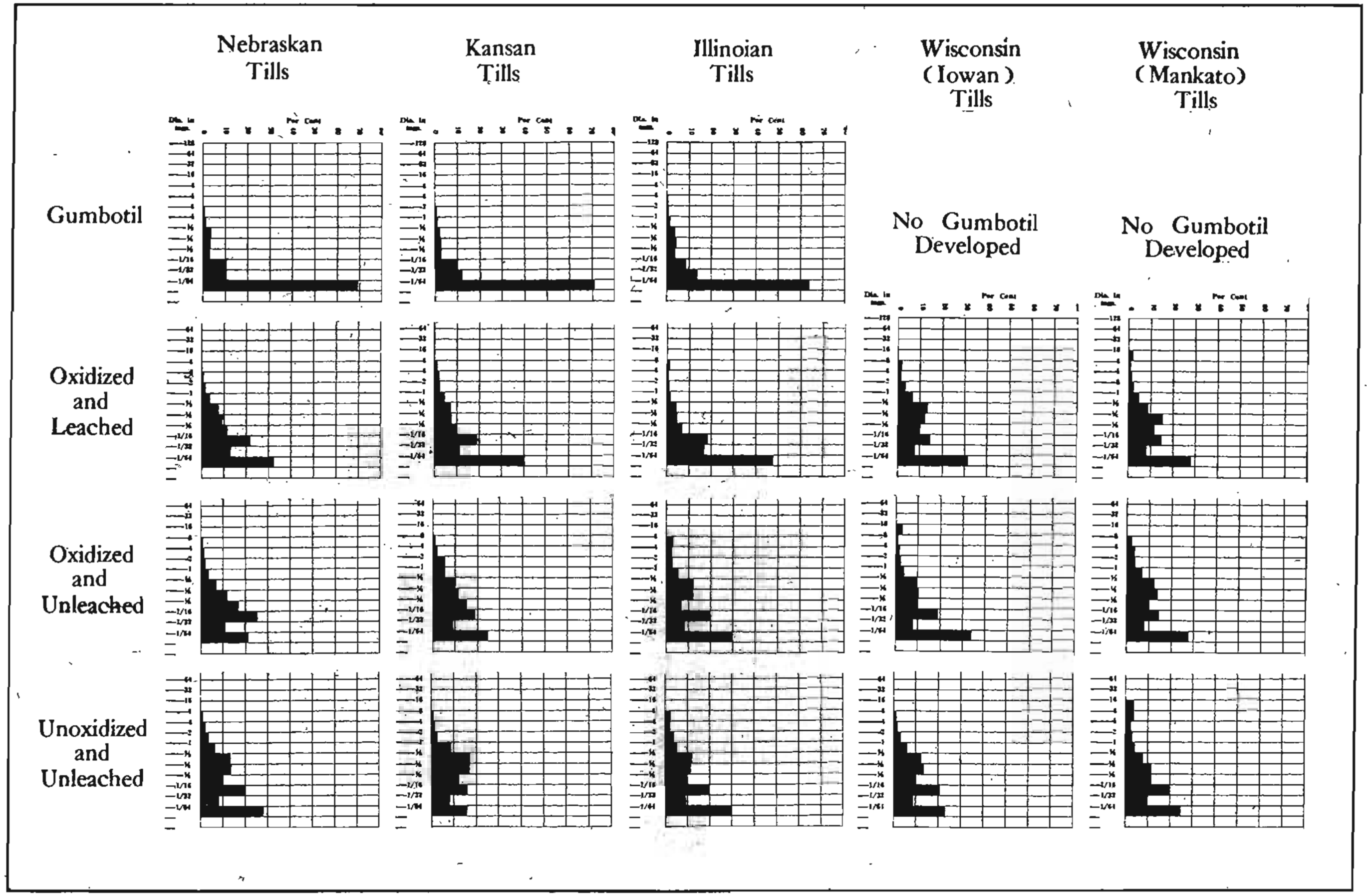

Figure 6. Graphs showing average mechanical analyses of the several tills in Iowa.

It is evident from study of the pebbles that no process of transportation or deposition could alter the rock content so as to increase the percentage of rocks resistant to ordinary processes of weathering, to lower the percentage of rocks which are composed of minerals which weather easily, and to remove almost all of the country rocks which constitute a high percentage of the unaltered till. Chemical weathering of the till is the only process by which this can be explained fully.

The shapes of the grains from the size grades between 1/8 and 1 millimeter in diameter were determined from a study of samples of both gumbotil and unleached and unoxidized till, (fig. 7). Previous studies of materials between 2-4, 4-8, and 8-16 millimeters in diameter have been made by Kay and Apfel. Their results are comparable to those of figure 7 but not so distinct since the size grades used would develop some angularity by disruption from larger dimensions. In studying the size grades between 1/8 and 1 millimeter in dimension, most of the grains used were siliceous or mineral grains which did not show good cleavage. The difference in shape between grains from the gumbotil and the unoxidized and unleached till is almost entirely due to the chemical solution of the thin edges which were more readily attacked by the weathering agents.

The Illinoian gumbotil was developed to an average thickness considerably less than that of the two older gumbotils. The average of 13 sections which seem to include the entire gumbotil phase is 3.8 feet, with a maximum thickness of 5 feet. This thickness contrasts noticeably with the thicknesses of the Nebraskan and Kansan gumbotils which have average thicknesses of 8 to 9 feet and

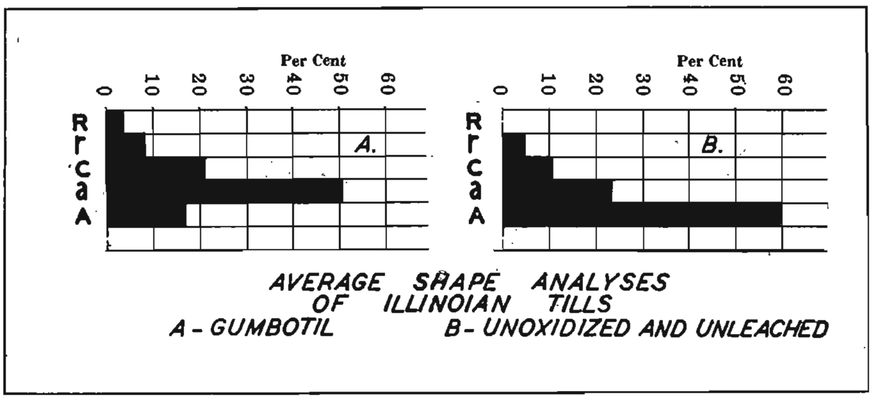

Figure 7. Graphs showing average shape and analyses of Illinoian gumbotil and unoxidized and unleached Illinoian till.

11 to 12 feet, respectively. This variation in thickness in the three gumbotils may be used as an aid in till differentiation in sections where the various drift phases appear to be complete. This criterion is especially indicative in isolated sections which topographically might be either Kansan or Illinoian. Figure 8 shows locations of some exposures of Kansan and Illinoian gumbotil in eastern Iowa.

Oxidized and Leached Illinoian Till

The oxidized and leached phase of the Illinoian till lies immediately below the Illinoian gumbotil, and blends into the gumbotil in such an intimate gradation that it is impractical to attempt to establish a sharp line of demarcation between the two phases, though they differ in their physical characteristics in several important particulars.

The color of the oxidized and leached phase is generally a light brownish yellow, appearing upon close inspection to be a mixture of light-gray and light-buff colors in areas of from 1 or 2 millimeters to several centimeters in diameter. The gray is around the root tubules and where organic materials appear to have been present and in the transition zone where interfingering of the overlying gumbotil produces a lighter hue. There are some ocherous concretionary centers which are rather sharply bounded. These may be the sites of calcareous pebbles which have disintegrated due to leaching.

The downward protuberances of the gumbotil into the transitional zone are seen to be restricted to the smaller joint planes and the vicinity of root tubules, with the larger and more open joints being stained a darker brown by iron. These areas may be distinguished from the more typical buff color of the oxidized and leached phase as a whole.

The mass texture of the oxidized and leached phase as compared to the gumbotil is distinct, but not so easily discerned as the color differences. It lacks the very characteristic sticky and plastic character of all wet gumbotils and does not have the minute starchy jointing so prevalent in gumbotil. The joints are spaced several centimeters apart and are not prominent if more closely spaced. The coarseness of the jointing is more marked near the base of the phase; the fine polyhedral pattern of gumbotil being restricted to the transitional zone. As a whole, this phase of the till is looser and more heterogeneous in mass texture than is the Illinoian gumbotil,

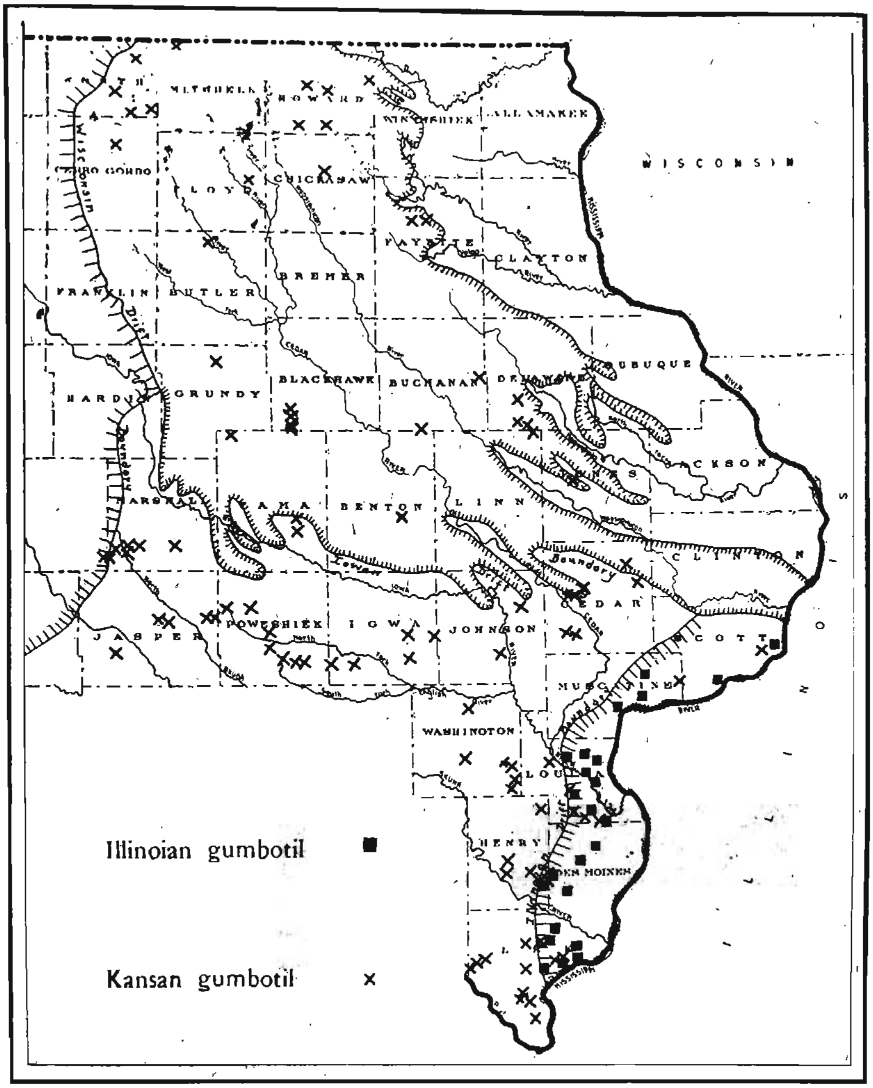

Figure 8. Map of eastern Iowa showing location of some exposures of ... and Kansan gumbotils.

a feature reflecting the greater sandiness and coarseness of the aggregate of the oxidized and leached phase.

The clastic texture of the oxidized and leached till is coarser than that of the gumbotil. The average of the mechanical analyses shows the maximum size grade finer than 1/64 millimeter in diameter, but, in general, this percentage is not as great as in the

Illinoian gumbotil (fig. 6). This lower percentage is due to the less complete disintegration by weathering of the coarser size grades than is found in the gumbotil.

The same variations as observed in the clastic texture of the different samples of gumbotil are present in the oxidized and leached till. The analysis of a sample of normal till would be much like the average of figure 6, but sandy till would show a distinct increase in the coarser size grades. Other analyses might show even more of the coarser material than of any intermediate grade between that and the fine.

The lithology of the Illinoian oxidized and leached till is represented by two analyses made by A. H. Dewey. One of the analyses is of pebbles from till below gumbotil and the other is from the till where the gumbotil has been eroded.

PEBBLE ANALYSIS OF ILLINOIAN TILLS

	Illinoian Till Gumbotil	Illinoian Till Oxidized and Leached[a]	Illinoian Till Oxidized and Leached[b]
Quartz	45.00	28.00	18.00
Chert	46.00	38.00	53.00
Quartzite	0.90		1.00
Granite	2.40	12.00	7.00
Basalt and Greenstone	3.30	14.00	15.00
Feldspar		2.00	
Sandstone	2.30	1.00	2.00
Felsite	0.10	5.00	4.00

a—Oxidized and leached till where gumbotil has been removed.
b—Oxidized and leached till below gumbotil.

These analyses, as would be anticipated, are very similar. They contrast with analyses of the gumbotil in that they contain a lower percentage of siliceous material and a greater percentage of other rocks, such as granite and basalt. They are similar to the gumbotil in that their maximum percentage is of siliceous and less soluble material. The presence of granites, basalts, etc., indicates that the weathering processes have not reduced the till to the stage of disintegration found in gumbotil. In many of these rocks, chiefly ferromagnesian rocks, there is an alteration by weathering at the surface along cracks, cleavage planes, etc. The schists are weakened so that they may be easily crumbled.

Shape analyses of this material do not show enough differences between this and the gumbotil to be of value. The differences are not more than might be found within the samples of oxidized and leached till themselves.

The oxidized and leached phase of the Illinoian till shows considerable variation in the sections where the overlying gumbotil permits measurements. The average depth is about 3 feet, with a maximum of 7 feet. This is slightly greater than the depth of leaching below the Nebraskan gumbotil, but less than the Kansan oxidized and leached phase. The Illinois Geological Survey has found this phase in Illinois to average 1 to 1½ feet in thickness.

Oxidized and Unleached Illinoian Till

The change in the till phases from oxidized and leached to oxidized and unleached is to be seen in a transition zone of varying thickness in which blocks of unleached till are bounded by major joint planes along which leaching has occurred. The line of response to acid may thus be found high, where blocks of till have not been latticed with joints to facilitate leaching, or low where prominent jointing has permitted flow of solutions. The depth of variation may be a foot or more.

The lower limits of the oxidized and unleached till are found in an even greater transitional zone in which massive blocks of the bluish unoxidized and unleached till, several feet in dimension, are bounded by the brown-stained zones of the joint planes. Especially in the upper part of the transition zone this downward penetration of oxidation along joint surfaces has produced such promiscuous interphasing that the result appears similar to the physical incorporation of masses of a lower, older material into an overriding, younger deposit. However, the gradual lessening of oxidation outward from the joint surfaces in the deeper parts of the transition zone, which finally narrows away, is convincing evidence of the true relationship. This zone in which there is greater or less interphasing may be many feet thick in sections great enough to permit unoxidized and unleached till to yet remain.

Just below the base of the upper transitional zone, between the oxidized and leached and the oxidized and unleached phases, there may be an indefinite thickness of till bearing secondary calcium carbonate concretions leached from the overlying noncalcareous phase. This enrichment normally forms nodules in the till for several feet below the base of the leached phase, and nodules, or an encrustment of white limy powder, along the joint surfaces to still greater depths.

The color of the oxidized and unleached phase is darker in tone than the leached till above. Along the joints there is commonly a crust of dark-brown, almost black, iron oxide, and this color penetrates the till for a short distance along the joints. Within the till are concretionary centers, 5 to 15 millimeters in diameter, with iron oxide the cementing material. From the center of each concretionary area the color grades outward to the lighter-buff color of the till.

The mass texture of the oxidized and unleached phase shows an increasing coarseness over the phases above. Below the transitional zone occurring at the top of this phase, the secondary joints become more insignificant, with the primary jointing being from 1 to 2 or 3 feet apart in the lower portions. The secondary or finer joints are spaced 5 to 10 centimeters apart and are fairly smooth and regular. The angles between the joints are usually somewhat greater or less than right angles. This reduction in the number and proximity of small joints is reflected in the increasing hardness of the till as it changes into the fresh, unaltered phase below which breaks into small pieces with conchoidal fracture due to the lack of preexistent fracture lines. Digging becomes increasingly difficult, a pick being necessary while in the oxidized and leached phase, and in the upper part of the oxidized and unleached phase a spade is often sufficient.

The clastic texture of the Illinoian oxidized and unleached till is strikingly different from that of either the oxidized and leached till or the gumbotil. A comparison of the histograms of the average mechanical analyses of the oxidized and unleached till with those of the oxidized and leached, and the gumbotil in figure 6, page 34, shows a greater decrease in the percentage of the size grade finer than 1/64 millimeter in diameter. The size grade between 1/64 and 1/32 millimeter in diameter shows a distinct decrease, the percentage generally lower than 10 percent. Instead of a general decrease in percentages with increase in size grades above 1/64 millimeters in diameter, there are two or three secondary maximums. Aside from the irregularities given, the only other difference from the analyses of the gumbotil and oxidized and leached till is the coarseness resulting from the lack of disruption by chemical weathering.

The most striking difference between the oxidized and unleached till and the gumbotil and oxidized and leached till is in the lithology. Although the gumbotil and oxidized and leached till contain a high percentage of siliceous material, a low percentage of granites and other such coarse crystallines, and a total absence of limestone, the oxidized and unleached till contains a high percentage of limestone, an increase in the percentage of granites and other such crystallines, and likewise a comparable decrease in the amount of siliceous material.

The abundance of such rocks as limestone, dolomite, granite, and basalt in the till indicates that the till has undergone very little chemical change. As further substantiation of the lack of chemical weathering, many of the easily soluble rocks such as limestone and dolomite still show scratches and striations made on their surfaces during transportation by the glacier.

Unoxidized and Unleached Illinoian Till

The basal phase of the Illinoian till is unoxidized and unleached, differing as a whole, from the phase above only in oxidation. Mineralogically and texturally, the two phases are much the same. Exposures of the fresh, unaltered bluish-gray till are uncommon, due partly to the rapidity with which the processes of oxidation attack a fresh surface and partly because in the characteristically thin Illinoian till, oxidation has penetrated to the base of the till in many areas. Thus, the Kansan gumbotil, or older surface, may be overlain by Illinoian oxidized and unleached till rather than unoxidized and unleached till.

The basal till phase is typically dark gray when dry, with a slightly bluish tint when wet. Within the mass are specks of brown color, and along some of the major joints are thin films of coloring matter. The drab color of the fresh till does not seem to be so much a reflection of the color of the bedrock in the general region as a product of the mass blending of all kinds and colors of rocks, and is therefore a somewhat standardized color for all fresh tills except in those localities where the local bedrock component of the till is abnormally high, as may be seen in a black shale locality in northwestern Iowa.

The mass texture of the unoxidized and unleached till is similar to the oxidized and unleached phase except for the concretionary zone in the latter. Major jointing is infrequent. The finer joint pattern is poorly developed, the joint surfaces being widely spaced, relative to the other phase, commonly being 10 to 20 centimeters apart. The material is gritty with considerable content of small pebbles, and where joint planes intersect these pebbles, the pebble impression is left sharply molded in one side when the till is separated along the plane.

The clastic texture of the unoxidized and unleached till is not distinctly different from that of the oxidized and unleached till. The average mechanical analyses of figure 6, page 34, show no greater variation from the oxidized and unleached till than would be present within the different samples of the unoxidized and unleached till. The slight difference seems to show a further decrease in the percentage of the material below 1/64 millimeter in diameter. However, the increase is not in the coarser grades, but in those grades between 1/8 and 1/2 millimeter in diameter.

The lithology of unoxidized and unleached till is almost the same as that of the oxidized and unleached till, for the only change which the oxidized and unleached till has undergone is the oxidation of the iron compounds which would not alter the rock content.

The percentage of rounding of the size grades between 1/4 and 2 millimeters in diameter is shown in figure 7, page 35. The grains studied were essentially of siliceous character and would be comparable to those studied from the gumbotil samples. This type of material was used since the chemical weathering would be recorded in rounding of the grains rather than disruption along cleavage planes or contact surfaces between mineral grains in such rocks as granites. The graph representing an average of five analyses shows almost 60 percent in the gumbotil. Likewise, the gumbotil shows more than twice the percentage of subangular and as much in the curvilinear as shown in the subangular grade of the unoxidized and unleached till. This shows the changes undergone in the rounding of sand grains during the formation of gumbotil.

THICKNESS OF THE ILLINOIAN DRIFT

Yarmouth interglacial time afforded abundant opportunity for erosion of the Kansan gumbotil plain, for the clearing out of some pre-Kansan valleys and for the forming of new drainage lines. Secondary courses and systems cut back into the gumbotil plain and must have become quite extensive before the Illinoian glacial advance. Chief among these streams in the region of present study were the Wapsipinicon, the Cedar-Iowa, and the Skunk. Because the Illinoian ice in Iowa was so near the limit of its extent, it probably was relatively thin and did not carry such a load of drift as it had farther east.

The outcrops in Lee County seem to show the thinnest and also the thickest sections of Illinoian till that have been found in the state. The exposure in sec. 35, Washington Township, (T. 68 N., R. 4 W.), a short distance northeast of Fort Madison, shows only 2 feet of till, all leached, between Kansan gumbotil below and Illinoian gumbotil above. The upper gumbotil is 4 feet thick.

On the other hand, the gully in the southeast corner of sec. 33, (T. 68 N., R. 4 W.), not much over a mile west of the previous one, shows evidences of a filling of Illinoian drift that may be over 100 feet thick. Dark unaltered till seems to extend downward nearly to the river level, about 170 feet from the upland. Of course, the possibility must be held in mind that some, perhaps much, of this is Kansan or older drift.

Between the extremes represented by these two sections are a number that probably approach nearer the average thickness of the Illinoian till. The ravine up which State highway 22 ascends from valley to upland near Davenport shows a thickness of 36 feet of till and gumbotil above the Kansan. The gully southeast of Grandview, in sec. 26, Grandview Township, (T. 75 N., R. 3 W.), Louisa County, has cut through at least 25 feet of Illinoian, apparently without reaching the base. The exposures near the Iowa River in sec. 4, Grandview Township, (T. 74 N., R. 3 W.), include 39 feet of unleached Illinoian till beneath 6 feet of till and gumbotil. Finally, the creekside exposure just south of New London shows 40 feet of Illinoian till well-delimited by the Kansan and Illinoian gumbotils. The sum of the evidence presented by the various outcroppings showing the entire thickness of the Illinoian till seems to point to a general estimate of 30 feet for the thickness of the Illinoian drift in Iowa. This is in agreement with estimates made in Illinois where this drift forms the surface cover.

These facts show that the Illinoian drift, while not so thick in the Iowa region as the Kansan or the Nebraskan, is nevertheless a drift sheet of large proportions. The truth of this statement is especially striking when we remember that the extreme western limit of this drift and of its parent glacier is about 1600 miles from the eastern source of the ice. A very copious supply of material and a tremendous impelling power must be conceived as having been behind the long reach of the Illinoian glacier. It must be kept in mind, of course, that very little, if any, of the mixture of rock and clay that make up the Illinoian drift of Iowa originated in the Labrador peninsula. Most of it doubtless came from west of the Indiana-Illinois state line, some of it perhaps brought there by the Kansan or the Nebraskan ice sheets as suggested before. The Illinoian till of western Illinois is much less calcareous where it overlies Pennsylvanian shales than where it rests on the Devonian limestones of the Rock Island region. This affords a concrete suggestion of the relatively short distance that most of the drift has traveled.

CHAPTER II

THE CENTRALIAN EPOCH (SERIES)
THE SANGAMON INTERGLACIAL AGE (STAGE)

- The Sangamon record
- Descriptions of Sangamon features
  - Illinoian gumbotil and related weathered zones
  - Sangamon sands and gravels
    - Weathered Illinoian upland gravels
  - Late Sangamon loess
  - Sangamon peat deposits and soils
  - Lake Calvin
- Sangamon erosion
  - Comparitive dissection of the Illinoian and Kansan drift plains
- Record of life in the Sangamon
- The Loveland formation
  - History of investigations of the Loveland formation
  - Loveland loess
    - Sections of Loveland loess
    - Laboratory studies of Loveland loess
      - Mechanical analyses
      - Mineral analyses
  - Loveland sands and gravels
  - Volcanic ash in the Loveland formation

THE SANGAMON RECORD

The Sangamon interglacial age (stage) followed the third continental glacier of the Pleistocene, the Illinoian. The Sangamon was preceded by two earlier interglacial ages, the Aftonian, which followed the Nebraskan ice age, and the Yarmouth, which followed the Kansan glaciation. The name Sangamon was used first by A. H. Worthen[11] for a soil zone lying between Illinoian drift and overlying Iowan loess, which he described in a report on Sangamon County, Illinois, written in 1873. The present usage of the term Sangamon to denote the interglacial age between Illinoian and Iowan glacial ages was introduced by Leverett[12] in 1898. Since the original description of this soil zone as representative of an interglacial age following the Illinoian glaciation, the physical record of this interval has become much better known by the recognition and investigation of weathered tills, weathered sands and gravels, late Sangamon loess, peat beds, and Lake Calvin.

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[11] Worthen, A. H., Geology of Sangamon County: Illinois Geol. Survey, vol. 5, pp. 306-319, 1873.

[12] Leverett, Frank, The weathered zone, (Sangamon), between the Iowan loess and Illinoian till sheet: Jour. Geology, vol. 6, pp. 171-181, 1898.

DESCRIPTIONS OF SANGAMON FEATURES

Illinoian Gumbotil and Related Weathered Zones

Following the deposition of the Illinoian till, weathering agents attacked the till and related deposits. Finally, where the topographic and other conditions were favorable, gumbotil was developed and beneath the gumbotil, an oxidized and leached zone and an oxidized and unleached zone were formed. The various steps in the formation of gumbotil and underlying weathered zones from fresh till are described on pages 31 to 41. The average thickness of Illinoian gumbotil is about 3 feet 6 inches to 4 feet.

The Illinoian gumbotil is the youngest of the three gumbotils developed from tills: namely, the Nebraskan gumbotil, the Kansan gumbotil, and the Illinoian gumbotil. The Illinoian gumbotil plain has not been dissected to the degree that the Nebraskan and Kansan gumbotil plains have been affected by erosion. The Illinoian upland is today a region of widespread undissected topography with most of its uneroded area in the position of the original Illinoian ground moraine plain. Late in the Sangamon interglacial age, after the Illinoian gumbotil and related materials had undergone in places considerable erosion, a loess, the late Sangamon loess, was deposited. This loess was weathered somewhat before the deposition of the oldest deposits of Wisconsin age.

Sangamon Sands and Gravels

Sands and gravels associated in age with the Sangamon interval are of several types and need not necessarily be contemporaneous in deposition. As in the case of the two older drift sheets, the Nebraskan and the Kansan, sands and gravels of glacial age were formed as pockets or lenses within or on the Illinoian drift, with subsequent weathering of these gravels during Sangamon time. Beyond the ice front, gravels were deposited as outwash and terrace gravels, related in time of deposition to the Illinoian glacier but weathered by processes active during the long interglacial period which followed. Gravels are found which are genetically related to the interglacial age, having their formation dependent upon the erosion of drift or bedrock materials during the interglacial age.

Weathered Illinoian Upland Gravels

During the deposition of Illinoian drift, masses of gravels were laid down in places as pockets or irregularly shaped deposits either within or upon the Illinoian till, being glacial in origin and contemporaneous in age with the till. Where these deposits lie upon or within the till, but near enough to the surface to be affected by the agencies of weathering, they were partially disintegrated and decomposed during Sangamon time.

Only one good example of such gravel is known to be available for study in Iowa. This exposure has been described by Kay and Miller.[13] It is in the E½ sec. 23, Bloomington Township, (T. 77 N., R. 2 W.), Muscatine County, near the Illinoian upland along the west side of the valley of Mad Creek.

The gravel here is an irregular pocket, exposed at the Illinoian drift surface, with a maximum depth of 35 feet. The gravel is iron-stained, particularly in the upper portions. Leaching is irregular in depth but averages about 7 feet in that part of the pit where minimum erosion has taken place. Variation in the lime content of the unaltered material, the irregularity of cover, and the noncalcareous sand which overlies the gravel in places contribute to the uncertainty of the depth of leaching of this upland deposit. An exposure of Illinoian upland gravel near the village of Sparta in Illinois is considered to be representative of the depth of leaching of upland gravels during Sangamon time, a depth of about 12 feet.

The bedding of the gravel ranges from horizontal to dips as high as 50 degrees, with the dipping in no predominant direction. Figure 9a is a diagrammatic representation of the size grade percentages of an average sample from the deposit. Figure 9b represents the lithologic percentages of the gravel between 16 and 32 millimeters in diameter.

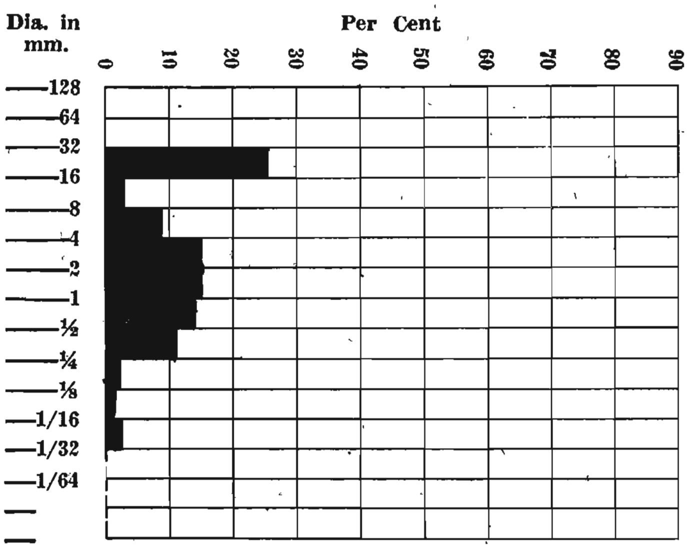
Late Sangamon Loess

Within the Illinoian drift area there are, in many places, two loesses on the Illinoian gumbotil and on eroded surfaces of Illinoian drift. The younger of these two loesses is the Peorian loess; the older loess has been named in Illinois the late Sangamon loess. In Iowa this older loess has been correlated by Kay[14] with the widespread Loveland loess of western Iowa, which is later than Kansan gumbotil erosion and is pre-Iowan in age. Leverett,[15] however, correlates the Loveland loess of western Iowa with pre-Illinoian

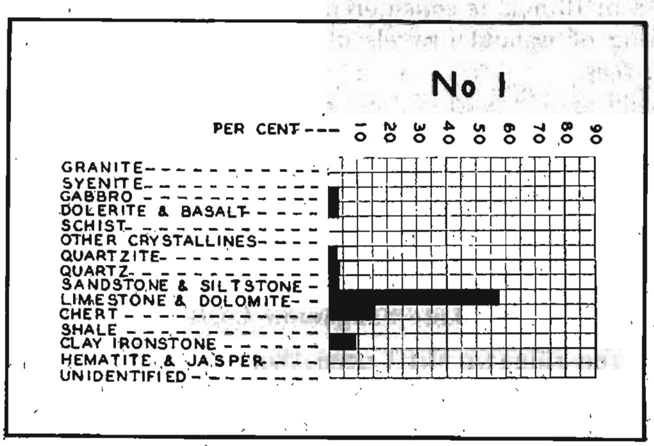
[13]Kay, G. F. and Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, pp. 88-92, 1941.

[14]Kay, G. F., Loveland loess: post-Illinoian, pre-Iowan in age: Science, new ser., vol. 68, pp. 482-483, 1928.

[15]Leverett, Frank, Loveland loess: pre-Illinoian, pre-Iowan in age: Science, new ser., vol. 69, pp. 551-552, 1929.



a



b

Figure 9. Graphs showing (a), mechanical analysis and (b), lithologic analysis of Illinoian upland gravel.

loess and questions the existence of a post-Illinoian, pre-Peorian loess. But in recent years this older loess on the Illinoian has been mapped widely by members of the Illinois and Iowa Geological Surveys. Although the Loveland loess of western, central, and southern Iowa outside the limits of the Illinoian area appears to be a single formation which was deposited in post-Illinoian, pre-Iowan time, Kay[16] has stated that in reality its lower part may be pre-Illinoian in age, and only its upper part post-Illinoian; and it may be that a part of the Loveland loess in western Iowa and adjacent areas was deposited during the Illinoian glacial age.

In the Iowan drift area of northeastern Iowa, Loveland loess

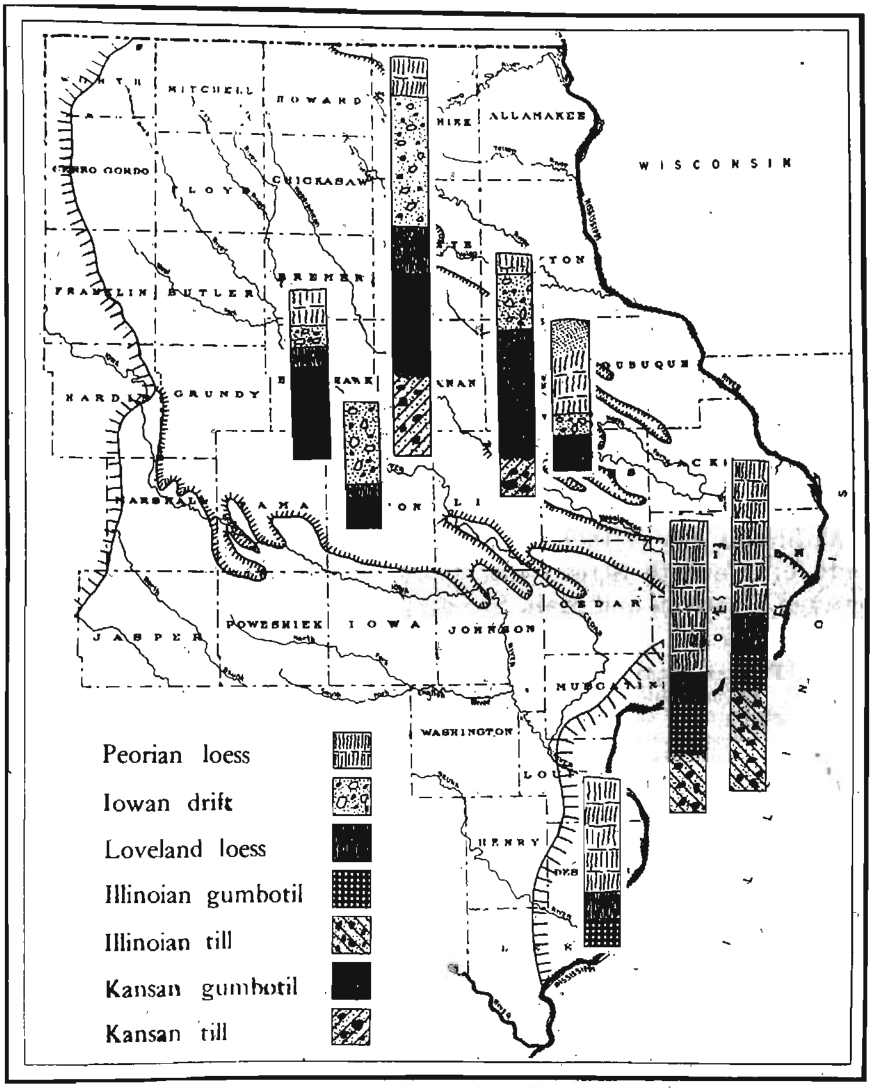


Figure 10. Diagram showing stratigraphic relationships of Loveland loess in eastern Iowa.

[16]Kay, G. F., Significance of post-Illinoian, pre-Iowan loess: Science, new ser., vol. 70, pp. 259-260, 1929.

is post-Kansan gumbotil erosion, pre-Iowan in age. Here the late Sangamon, or Loveland loess is overlain by calcareous Iowan till. In the Illinoian area of southeastern Iowa, the Loveland loess is post-Illinoian gumbotil, pre-Peorian loess in age. These relationships are graphically shown in figure 10.

The Loveland loess of the Illinoian drift area in Iowa has now been established by stratigraphic methods as being much younger than the Illinoian glacial drift and older than the Iowan glacial drift; that is, it is late Sangamon in age. The loess was deposited after the development over wide areas, chiefly by chemical weathering, of gumbotil more than 3 feet thick on the Illinoian till. Before the advance of the Iowan drift sheet there was sufficient time for the loess to be leached to a depth of several feet.

Several good exposures of Loveland or late Sangamon loess are found in Scott County. About 1 mile west of Davenport, on State highway 22, in the SE¼ sec. 31, Rockingham Township, (T. 78 N., R. 3 E.), a road cut shows a succession of Illinoian gumbotil, Loveland loess, and Peorian loess. The gumbotil is 3 feet thick, gray, and typical in character. The Loveland is leached, brown in color, has some secondary calcium carbonate, and is here about 1½ feet thick. This is overlain locally by 8 feet of Peorian loess, gray below and buff above.

Within the city of Davenport, good sections of Loveland loess are south of Eleventh Street, just south of the high school building between Harrison and Main Streets. Here a section shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff colored, unleached	15	
Sangamon interglacial stage:		
Loess, Loveland, purplish colored, leached	4	
Illinoian glacial stage:		
Till, reddish, oxidized, leached	3	

Many other exposures have been examined; the physical characters of the loess have been found to differ but little in the various sections.

Sangamon Peat Deposits and Soils

Since the days of Winchell, Chamberlin, and McGee, peat beds have been used by glacial geologists as indicative of interglacial ages. Conditions which permit the slow accumulation of compact vegetal matter in areas protected from erosion are not in themselves criteria of subtropical or even temperate climate, but merely indicate favorable burial conditions of vegetal debris over a considerable period of time. It is the study of such deposits in relation to their surrounding materials, their topographic positions, the estimated rate of accumulation, and the climatic environment indicated by the plant fragments and pollen grains which enable the geologist and paleobotanist to interpret the conditions which prevailed during the interglacial age in which the peat was deposited.

The poorly drained topographic conditions which exist following deposition of a glacial drift sheet are ideal for bog and swamp formation, and the accumulation of small isolated areas of peat in the depressions distributed over a fresh till plain is probably far more prevalent than the few peat occurrences known on the older drifts would seem to show. Peat deposits in various stages of formation and burial are widely prevalent over the young, poorly drained Mankato drift, with often as many as four or five distinct peat bogs per square mile. There is little reason to believe that the surface environment of the older drifts including the Illinoian differed essentially either in topography or climate from that which has existed in north-central Iowa since the retreat of the Des Moines lobe.

The best section seen in the Illinoian drift area of Iowa to show Sangamon peat is in the southwest corner of sec. 10, Port Louisa Township, (T. 74 N., R. 3 W.), Louisa County. It is in the northwest valley wall of the Iowa River where a cut has been made along U. S. highway 61. Here the section is as follows:

	Feet	Inches
Sand, dune-like, white and yellow, little if any calcareous material, some laminations	15	
Peorian intraglacial substage:		
Loess, unleached, buff colored, some fossils, fine-grained. Grades into sand above	8	
Sangamon interglacial stage:		
Peat, the upper 2 feet almost wholly woody, the lower 3 feet highly carbonaceous and intimately related to the underlying loess	5	
Loess, Loveland, leached, sticky, tenacious, drab to dark bluish clay, some sand grains and small pebbles. Exposed	3	

Here the Loveland loess was deposited in an eroded area of the Illinoian drift plain and the peat accumulated in an undrained depression on the loess surface. The Illinoian gumbotil elevation about 5 miles to the north, in sec. 26, Grandview Township, (T. 75 N., R. 3 W.), is 650 feet above sea level. The elevation of the peat on the loess is about 600 feet.

Samples of the peat from this section were collected by Geo. H. Lane,[17] and a study of the pollen grains found in the peat at 2-inch intervals makes possible a climatic and floral interpretation of the conditions prevailing during the closing stages of the Sangamon interglacial age. Percentages of the seven most important pollen types from one of the sections, figured at each 2-inch level in vertical section, are shown in figure 11. Lane's study of pollen types in three different sections through the peat has been summarized as follows:

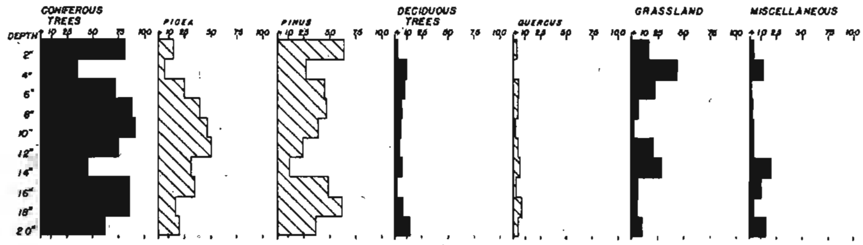


Figure 11. Graph showing pollen percentages in a Sangamon peat bed. (After Geo. H. Lane.)

"It would appear that climatic conditions toward the end of the interglacial interval fluctuated considerably. The uppermost of these peaks of grassland and deciduous tree pollen, (fig. 11), may represent the same sort of brief climatic amelioration as was noted toward the end of the Aftonian interglacial period. The work of Jessen and Milther, (German botanists), in which this feature appears so prominently, was on peat of the last interglacial in Europe which may be contemporaneous with the Sangamon in this country.

"There is, however, no positive evidence that this peat was formed at the very end of interglacial time. The high values of grassland and oak pollen are accompanied by considerable pine and some spruce. These might be interpreted as a mixed oak-pine savannah at some earlier stage in interglacial time. However, the absence of such forms from Voss' long series of materials from nearby stations in Illinois would lead one to doubt this conclusion. It seems more likely that the Iowan peat is more recent than the Illinois beds and consequently that it developed quite late in Sangamon time."

This interpretation based on floral evidence is in harmony with the stratigraphic position of the peat, for the Loveland loess which is found on the Illinoian drift is a feature of late Sangamon time, having been deposited after the formation and erosion of the Illinoian gumbotil and only enough before the deposition of Iowan or Peorian loess to have acquired a youthful profile of weathering. In point of time, it would seem that the peat bed under discussion is equivalent to the soil zone on the Loveland loess in the Farm Creek section, near Peoria, Illinois.

Another section showing peat on Loveland loess is in Scott

[17]Lane, G. H., Pollen analyses of interglacial peats of Iowa: Iowa Geol. Survey, vol. 37, pp. 256-260, 1941.

County. The peat is exposed in a railroad cut of the Chicago, Rock Island and Pacific Railway, just south of the viaduct where highway 22 crossed the railroad just within the western limits of the city of Davenport. This section, which was first described by Pratt,[18] is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, full of concretions, the lower 3 to 5 feet bluish gray, fossiliferous	20	
Sangamon interglacial stage:		
Peat, brownish black, some pieces of wood several inches in diameter	1-3	
Loess, Loveland, dark brown in color	3-4	
Illinoian glacial stage:		
Till, leached, oxidized. Exposed	3	

In the description of this section by Pratt at the time of excavation, the dried peat was found to be woody enough to burn, but constituted a very poor fuel. The peat moss *Hypnum aduncum* was identified as one constituent, along with unspecified coniferous woods.

A 2-foot bed of peat occurs between Peorian loess and Illinoian till near the northwest corner of the SW¼ sec. 34, Sweetland Township, (T. 78 N., R. 1 W.), and a thin bed has been seen in the NE¼ sec. 15, Bloomington Township, (T. 77 N., R. 2 W.), both of Muscatine County.

The occurrence of Sangamon peat and soil zones in Illinois and southeastern Iowa is discussed by Leverett.[19] Some of these have attained considerable depth. In general, the formation of Sangamon peat and soil zones has been more restricted in western Illinois and southeastern Iowa than in more easterly areas of the Illinois drift, due to the improved drainage conditions near the valley of the Mississippi River.

Numerous sections of Loveland or late Sangamon loess show the development of a soil zone at the top of the loess, which is usually overlain by calcareous Peorian loess. Such a development is well displayed in an exposure in the NW¼ sec. 22, Lincoln Township, (T. 79 N., R. 4 E.), Scott County. Here the Loveland loess and soil zone is exposed for about 25 yards along a road cut. The complete section is:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff in color in the upper part, gray and un-		

[18]Pratt, W. H., Report on a geological examination of the section of the bluff recently exposed by the C. R. I. & P. R. R.: Davenport Acad. Sci. Proc., vol. 1, pp. 96-99, 1867-1876.

[19]Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 125-130, 1899.

	Feet	Inches
leached in the basal part, iron tubules, many concretions; relief	30	
Sangamon interglacial stage:		
Soil zone, carbonaceous, loess-like, dark brown, leached but with secondary concretions	1	
Loess, Loveland, leached, brown, laminated, secondary concretions. Grades into soil above	2-3	

The surface of the Loveland loess here is somewhat irregular and this fact probably facilitated the accumulation of carbonaceous soil material. The soil layer is not uniform in thickness.

Outside of the Illinoian drift area, a fine exposure of soil on Loveland loess is at the edge of the Iowan till plain where a deep cut has exposed the two loesses separated by the Loveland soil. This section occurs along the west line of the NE¼SE¼ sec. 27, Madison Township, (T. 81 N., R. 7 W.), Johnson County, and is about one-tenth of a mile north of Mid-River Station on the Cedar Rapids and Iowa City Railway. The section is given below:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, buff colored	3	
Loess, unleached, buff colored, somewhat sandy	22	
Sangamon interglacial stage:		
Soil zone, leached, highly carbonaceous, very dark gray to grayish black	1	
Loess, Loveland, leached, mottled chocolate-brown and gray	3	6

This soil zone is seen for a distance of 150 feet along the base of the slope.

An excellent section exhibiting Sangamon soil directly upon Illinoian gumbotil is along a small ravine in the Illinoian upland near Grandview in Louisa County. It is just east of the road in the SW¼ sec. 26, Grandview Township, (T. 75 N., R. 3 W.). Here is a fairly complete section of materials representing the Centralian epoch. Reference to the section was made on page 26 of this report. The soil relations are as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, leached, lower part gray with iron tubules, thickness to upland	10-20	
Sangamon interglacial stage:		
Soil zone, highly carbonaceous, dark to black, compact	1	6
Illinoian glacial stage:		
Gumbotil, typical, dark gray to drab on a dry surface; sticky, tenacious, leached, few pebbles, grades into soil above	3	6

This section was visited by the soil men of the U. S. Department of Agriculture and of the Illinois Soil Survey. The soil zone above the Illinoian gumbotil was described by them as typical of the podzolized soil which has a widespread development on the Illinoian gumbotil uplands to the east and north of the Illinoian area in Iowa. It is the "A zone" of the soil profile as interpreted by the Illinoian Geological Survey, being a further development of weathering of the surficial gumbotil materials.

Lake Calvin

The Lake Calvin basin is an area in southeastern Iowa covering parts of Cedar, Johnson, Muscatine, Washington and Louisa Counties. It is bounded on the southeast by the Illinoian moraine and drift plain, and elsewhere by the uplands of the Kansan drift. Chiefly, it is an area lying roughly parallel to the Iowa and Cedar Rivers, Iowa City delimiting the main arm along the Iowa River to the north, and Moscow being at the north limit of the main arm along the Cedar River. The basin terminates on the south at the junction of the two rivers, at Columbus Junction, in Louisa County (fig. 12). The lake is thought to have been formed during the Illinoian glacial age by the damming of the Iowa and Cedar Rivers and the displacement of the Mississippi River by Illinoian ice. The pre-Illinoian history of the streams which were affected, the changes which resulted in glacial Lake Calvin and the subsequent drainage of that lake, and the effect of later glaciation on the basin have all been studied in considerable detail.

Leighton[20] has interpreted the pre-Illinoian history of the Iowa River as follows:

"At the time of the encroachment of the Kansan ice-sheet, the topography and drainage were entirely different from the topography and drainage of the present. A wide valley crossed the southern part of the county, from west to east, and a notable rock divide lay to the northeast. This was covered by the Kansan ice, which, on melting, left drift which filled the low places and leveled off the high ones, producing a flat-lying plain. Upon this the surplus waters of the undrained depressions and surrounding areas sought the lowest outlet and ultimately established Iowa River. The course that the river now has is in general the course that marked the lowest outlet in the beginning.

". . . As Iowa River channeled its course deeper through the drift, it superimposed itself upon the rock-divides in the area of high bedrock. Having established its course it could not avoid them. The drift in the segment upstream and in the segment downstream from high bedrock, being much softer than the rock, offered extraordinary conditions for variable development of the valley. The resistance of the limestone permitted the river, in the upper segment of drift, to reach grade and to widen the valley by lateral planation while the gorge was being cut. In the segment downstream from bedrock, conditions worked differently, but the result was quite similar. The river cut so much more rapidly in the drift than it did in the rock that it

[20]Leighton, M. M., The Pleistocene history of the Iowa River Valley: Iowa Geol. Survey, vol. 25, pp. 163-167, 1915.

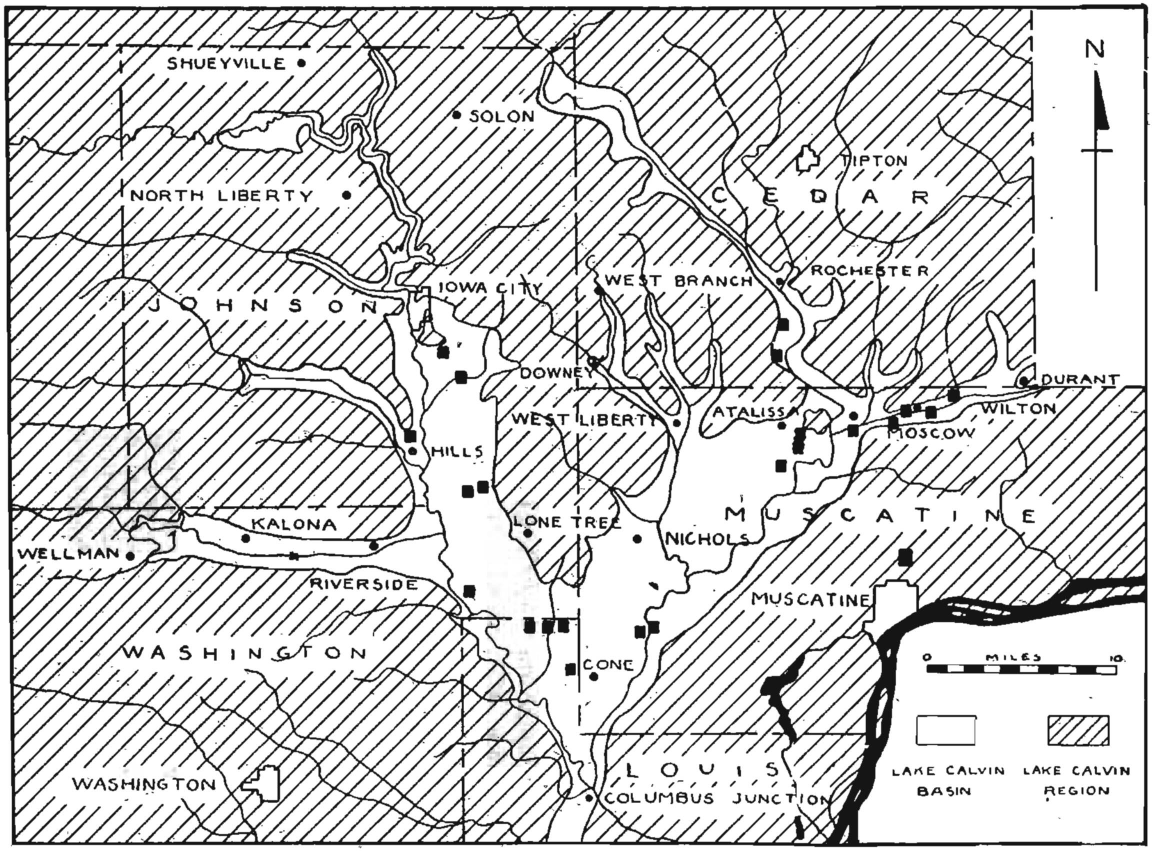


Figure 12. Sketch map of the Lake Calvin area showing the location and extent of the lake. The small squares show the location of exposures described by Schoewe. (Map by Schoewe.)

reached grade sooner and had time to widen that segment to an old-age stage of development.

". . . Contemporaneously with the carving of the valley, tributaries developed. Some of those tributary to the gorge cut considerably into rock whereas those tributary to the wide portions of the valley are cut mainly, if not altogether in drift. The result of the development of all these has been to dissect the original Kansan plain into many valleys and divides, and so completely to change its glacial aspect to an erosional one."

The advent of the Illinoian glacier, which moved a short distance into the state from the east, blocked the lower reaches of the Iowa River, causing its waters to be added to that of the Mississippi and Cedar Rivers until the water level in the ice-dammed basin reached the height of the now abandoned channel which flowed first southwest of the basin and then back to the unfilled channel of the Mississippi somewhere to the south. This channel has been described in detail by Leverett.[21]

That the Cedar River had a pre-Illinoian history similar to that of the Iowa River has been suggested by Norton.[22] It is thought that the post-Kansan Cedar River followed for a considerable part of its course a bedrock channel which had been carved before the Kansan ice invasion. Norton reviews the evidence in the following paragraph:

"The breadth and sloping sides of the wide reaches of the Cedar are evidences of great age, but in themselves alone these characteristics do not imply a preglacial or pre-Kansan origin. Valleys as broad in southwestern Iowa have been found to be post-Kansan by the geologists who have studied that field. But, while the latter are cut in drift, the former are cut in solid rock in large measure. Taking into consideration both the quantity and the hardness of the material excavated, and, in especial, the fact that the drift lies unconformable on the slopes of rock which form the sides of the valley, the conclusion is inevitable that the wide (bedrock) valleys of the Cedar are at least pre-Kansan in age, and may, perhaps, be even preglacial."

As with the Iowa River, the Illinoian ice front blocked the normal drainage of the Cedar River simultaneously with the shunting of the Mississippi River westward, and these two diverted streams flowed to the southwest along the ice escarpment to the Iowa River Valley where the junction of the ice with the Kansan highlands caused an impounding of the waters to a maximum depth of about 140 feet.

Thus, the waters which filled the blocked pre-Illinoian valleys of the Iowa and Cedar Rivers came from those rivers and the Mississippi with its neighboring tributaries as well as from the glacial waters of the Illinoian ice front.

The duration of this body of water as Lake Calvin, the course or

[21]Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 89-97, 1899.
[22]Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, vol. 11, p. 291, 1901.

courses of its drainage, and the contemporaneous history of the Mississippi River are problems that have not as yet been satisfactorily solved. The duration and drainage of Lake Calvin, and the position of the Mississippi River during the Sangamon interglacial age would seem to be related. Two somewhat differing views regarding these relationships have been put forward.

Schoewe[23] is of the opinion that Lake Calvin must have lasted until just previous to the Iowan glacial advance. Attention is called to the amount and type of sediment in the lake basin, the gumbotil relations and the contact of the high and low terraces, as evidence of this long duration for the lake. The abandoned channel of Leverett to the south of the basin is suggested as the outlet. This view requires the continued flow of the Mississippi River drainage into its Goose Lake channel inlet, through the filled Lake Calvin basin, and out of the Leverett channel throughout Illinoian glacial and most of Sangamon interglacial time.

Trowbridge, Williams, Frye and Swenson,[24] and Leverett[25] are agreed that Lake Calvin was of short duration and that contemporaneously with the retreat of the Illinoian ice to the eastward, the Mississippi River drainage probably reverted to the Illinois River drainageway in west-central Illinois, where there is some evidence of its occupancy during the Yarmouth interval, and that it remained there during Sangamon time. According to their findings, the Mississippi River left the present Illinois River drainage only during the actual occupation of southeastern Iowa and western Illinois by the Illinoian ice. This argues for a relatively short duration of the lake, equal only to the time the ice front remained in Iowa. By these authors, Lake Calvin is thought to have been drained by the development of the Iowa-Cedar Valley across the fresh Illinoian drift of southeastern Iowa. As this drainage was controlled both by the Des Moines rapids in the present Mississippi River, and by its distance at that time from the master stream occupying the Illinois River valley, drainage relief on the Illinoian drift plain in Iowa was slight, and gumbotil was able to form very close to the valley walls.

SANGAMON EROSION

The Illinoian drift plain forms the surface, or lies just beneath

[23]Schoewe, W. H., The origin and history of extinct Lake Calvin: Iowa Geol. Survey, vol. 29, pp. 208-218, 1920.

[24]Trowbridge, A. C., Williams, A. J., Frye, J. C., and Swenson, F. A., The Pleistocene history of Mississippi River: (Abstract), Iowa Acad. Sci. Proc., vol. 48, p. 296, 1941.

[25]Leverett, Frank, Re-establishment of the Mississippi River after the Illinoian glaciation (Abstract), Geol. Soc. America Bull., vol. 52, p. 1940, 1941; Shifting of the Mississippi River relation to glaciation: Geol. Soc. America Bull., vol. 53, pp. 1283-1298, 1942.

a variable cover of Peorian and late Sangamon loess, over much of Illinois and an area in the southeast part of Iowa. It is therefore possible to study with little difficulty the post-Illinoian, pre-Peorian, and entire post-Illinoian dissection of the drift sheet. That the stage of erosion found on the Illinoian is distinct from the Kansan till plain dissection, is readily apparent in those areas where the two drift plains are in conjunction.

Comparative Dissection of the Illinoian and Kansas Drift Plains

In southeastern Iowa, before the Illinoian drift had been determined to extend into Iowa, the difference in the two topographies was noted but not satisfactorily explained. Leverett[26] says:

"Prior to the discovery of the extension of the Illinois lobe into southeastern Iowa it had been noted by Chamberlin, as well as by the writer, that southern Iowa presents a more eroded appearance than western Illinois and the southeastern counties of Iowa, and the matter was discussed as a remarkable feature. In the district outside the limits of the Illinoian the original drift plain is preserved only in narrow strips along the divides, estimated to comprise scarcely one-fourth of the surface, while in the district covered by the Illinoian drifts the remnants are far more extensive comprising apparently more than half the surface. The branching of drainage lines is also carried to markedly greater maturity in the Kansan than in the Illinoian drift."

The Illinoian drift plain is much less dissected than the Kansan drift plain. A reference to the topographic map of a representative area of each of these drift sheets illustrates their differences as to erosion and surface relief. The Illinoian drift plain in Iowa shows comparatively little erosion. Large areas remain as remnants of the featureless plain of original deposition. These are the broad "upland divides." Nearer the drift border, or near master drainage lines, this upland plain aspect is less apparent, but the relatively unreduced stage of the terrain, the youth of the valleys and the lack of well established drainage provinces are convincing evidences of the comparative youthfulness of the region.

In contrast, the characteristic appearance of the Kansan drift surface shows few areas of flat uplands, or tabular divides. Where such areas remain, they are small as compared to the upland plains of the Illinoian drift. The Kansan valleys are broad and moderately deep, with wide, flaring walls merging with remnants of the uplands. The streams in the smaller valleys have not reached grade and they have cut gullied inner valleys. The larger streams have built floodplains and have widened the valley floor in places by lateral planation and meanders have developed. The drainage pat-

[26]Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 121, 1899.

tern is more complete than that of the Illinoian drift, and the graded condition of the larger Kansan streams indicates advanced adjustment of drainage conditions.

The stage of valley cutting on the Illinoian plain during Sangamon time does not seem to be in accord with other evidences of the duration of the Sangamon. The leaching of the gravels and the thickness of gumbotil which formed on the uneroded till uplands indicates a longer interglacial age following the disappearance of the Illinoian ice than the dissection of the till plain alone seems to indicate. A low altitude and slack drainage for the till plain is in keeping with widespread peat and soil accumulation on the drift surface in Illinois.

RECORD OF LIFE IN THE SANGAMON

Because of the scarcity of fossiliferous deposits which can be definitely ascertained as Sangamon in age, little is known of the fauna and flora in Iowa of this interglacial age. Loveland loess, of which the upper part at least is Sangamon in age, is known to be sparsely fossiliferous.[27] The invertebrate fauna collected from three Loveland loess and silt deposits in Cherokee County in northwestern Iowa have been studied by Cameron. The following lists and interpretations have been taken from unpublished reports by Kay and Cameron.

Two miles west of Larrabee, Cherokee County, a Loveland loess exposure yielded the following mollusks:

Hendersonia occulta
Gonyodiscus cronkhitei anthonyi
Cochlieopa lubrica
Succinea avara
Succinea cf. S. ovalis
Polygyra cf. P. multilineata
Fossaria parva

The most indicative of these, *Hendersonia occulta,* is a snail with habitat on upland slopes and deeply shaded bluffs. Of the 40 specimens collected from the locality, 22 belonged to this species. The fossil assemblage points to loess deposition in deep woods in a temperate climate. A seepy place or small pond probably was present at one time at the place where the collection was made.

From a Loveland silt deposit south of Cherokee in the SW¼ sec. 1, Pilot Township, (T. 91 N., R. 40 W.), Cherokee County, the following forms were found:

[27]Kay, G. F., Recent studies of the Pleistocene in western Iowa: (Abstract), Geol. Soc. America Bull., vol. 35, p. 78, 1924.

Pisidium sp.
Planorbis sp.
Fossaria sp.
Pupoides marginatus
Succinea avara
Gastrocopta armifera
Vallonia gracilicosta
Hawaii minusculus
Pupilla muscorum?
Gastrocopta procera

This assortment suggests that a mixture of fresh water and terrestrial forms were washed into this deposit. The land forms consist of snails from both forest and prairie habitats.

From a neighboring Loveland section in the SE¼ sec. 11, Pilot Township, (T. 91 N., R. 40 W.), Cherokee County, these fossils were collected:

Gastrocopta armifera
Pupoides marginatus
Segmentina armigera
Euconulus fulvus
Vallonia gracilicosta
Hawaii minusculus
Gastrocopta procera
Pupilla muscorum?

Here the shells were no doubt washed into a silt deposit. Both terrestrial and fresh water species with a wide range of habitat and geographic distribution are represented.

Baker has listed the mollusks collected from a Loveland section in Des Moines County, described earlier by Keyes.[28] These are:

Pyramidula perspectiva
Pyramidula cronkhitei anthonyi
Pupilla muscorum
Succinea obliqua
Helicina occulta
Galba obrussa

Additional species from this section reported by Leverett[29] are:

Succinea lineata
Oreohelix iowensis

Several Iowa localities have produced fragmentary vertebrate remains of Sangamon age. From Muscatine County Udden[30] reported elephant bones from a Sangamon peat deposit in the center of the SW¼ sec. 12, Sweetland Township, (T. 77 N., R. 1 W.). He also described in detail a partial mastodon or elephant skeleton[31]

[28]Baker, C. L., The life of the Pleistocene or Glacial period: Contributions from Mus. of Nat. Hist., No. 7, Univ. of Illinois, pp. 286-287, 1920.
Keyes, C. R., Glacial scorings in Iowa: Iowa Geol. Survey, vol. 3, p. 156, 1895.
[29]Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 169, 1899.
[30]Udden, J. A., The geology of Muscatine County: Iowa Geol. Survey, vol. 9, p. 350, 1899.
[31]Udden, J. A., *op. cit.* p. 352.

found by Calvin in a clay and sand deposit of Lake Calvin, on Mud Creek, near Wilton. Present views on the age of these deposits may give the fossils a late Illinoian age rather than Sangamon age, as described by Calvin and Udden.

A tusk, teeth and other bones of *Elephas primigenius* were found in late Sangamon loess along the Chicago, Rock Island and Pacific Railway, west of Davenport. This section has been described earlier in this report, under the heading of Sangamon peat, pages 52 and 53.

Elephant bones, including a lower jaw, were found in Sangamon peat along Otter Creek, near the center of the NW¼ sec. 25, Morning Sun Township, (T. 73 N., R. 4 W.), Louisa County.[32] A deer's antler was reported from a neighboring locality, in this same Sangamon horizon.

The Loveland terrace gravels of western Iowa have yielded some vertebrate fossils but Sangamon fossils from the state as a whole are too few and fragmentary to justify any interpretations as to the climate and fauna in general. Perhaps a better basis for generalization on the Sangamon climate is the study of pollens in Sangamon peat made by Lane, and presented on pages 51 and 52 of this report. While the peat deposit studied is thought to represent only the closing stages of the interglacial interval, the sequence of percentages of grassland, oak and other types of pollen suggests a climate in late Sangamon time of coniferous dominance, with the exception of a fluctuation toward the close of the interglacial to a milder, grassland-oak dominance.

Perhaps the best known fossil bearing horizon of Sangamon age in the Upper Mississippi Valley is the richly fossiliferous soil zone at the top of the Loveland loess and below the Peorian loess, in Nebraska.[33]

This zone represents the interval between the deposition of the two loesses, and may have been developed during beginning Iowan glaciation as well as in late Sangamon time. The vertebrates from this soil horizon include:

Citellus cf. elegans (Kennicott)
Thomomys talpoides (Richardson)
Mustela vison Schreber
Archidiskodon imperator (Leidy)
Archidiskodon imperator maibeni (Barbour)
Parelephas columbi (Falconer)
Platygonus sp.
Camelops sp.
Bison sp.

[32]Udden, J. A., The geology of Louisa County: Iowa Geol. Survey, vol. 11, p. 110, 1901.
[33]Lugn, A. L., and Schultz, C. B., The geology and mammalian fauna of the Pleistocene of Nebraska: Nebraska State Mus., vol. 1, Bull. 41, pp. 359-360, 1934.

THE LOVELAND FORMATION

History of Investigations of the Loveland Formation

The name Loveland was used first by Shimek[34] for a deposit in western Iowa. The type section of this formation is at Loveland, Pottawattamie County. In a later paper[35] Shimek described the Loveland deposit as follows:

"A heavy, compact, reddish, (especially on exposure to the air), or sometimes yellowish silt which, when dry, is hard with a tendency to break into blocks like a joint clay, and, when wet, becomes very tough and sticky; and hence, is sometimes called a gumbo."

By earlier workers this formation was thought to be related to the widespread buff loess of the region, but Shimek believed that it was a fluvioglacial deposit "formed during the melting of the Kansan ice." He considered its distribution to be as general as that of the Kansan drift. Since the original descriptions of the formation, its deposits have been studied and its characteristics and relationships described by geologists of the Iowa Geological Survey.[36]

In a paper, "Recent studies of the Pleistocene in western Iowa," Kay, in 1924, made the following statement with regard to the Loveland of western Iowa:

"In many places it is calcareous and contains calcium carbonate concretions, many of which are from three to six inches in diameter; a few were seen with greatest diameter more than twelve 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 surfaces of Kansan till."

In a later paper, "Loveland loess: post-Illinoian, pre-Iowan in age," published in 1928, Kay referred to his statement of 1924 as follows:

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[34]Shimek, Bohumil, Aftonian sands and gravels in western Iowa: Geol. Soc. America Bull., vol. 20, footnote p. 405, 1909.

[35]Shimek, Bohumil, Geology of Harrison and Monona Counties: Iowa Geol. Survey, vol. 20, pp. 371-375, 1910.

[36]Kay, G. F., Recent studies of the Pleistocene in western Iowa: Geol. Soc. America Bull., vol. 35, pp. 71-73, 1924; Loveland loess, post-Illinoian, pre-Iowan in age: Science, new ser., vol. 68, pp. 482-483, 1928; Significance of post-Illinoian, pre-Iowan loess: Science, new ser., vol. 70, pp. 259-260, 1929; with Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, pp. 277-281, 1929; with Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, pp. 98-118, 1941.

Carman, J. E., Furthur studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, pp. 49-52, 1931.

"This statement was based upon investigations in a comparatively limited region near the type section, which is on the east slope of the Missouri River valley. The views to be presented in this brief paper are the result of detailed studies of the Loveland formation in widely distributed exposures in Iowa. The characteristics, distribution, origin and age of the deposits of Loveland time in Iowa have been determined and will be described fully in a paper now in preparation.

"In western and northwestern Iowa, at least, the Loveland deposits consist not alone of loess, but also of widespread silts, sands and gravels. While the Loveland silts, sands and gravels were being deposited in valleys, the Loveland loess was accumulating on adjacent slopes and uplands.

"With the writer's knowledge of the characteristics and relationships of the Loveland loess and associated silts, sands and gravels in western Iowa as a background, he examined similar deposits in that part of northwestern Iowa which lies west of the Des Moines lobe of the Wisconsin terminal moraine, where within the last few years Frank Leverett, J. E. Carman and the writer have found evidence of a post-Kansan, pre-Peorian drift which is apparently of the same age as the Iowan drift of northeastern Iowa. Within this Iowan drift area of northwestern Iowa the Loveland loess, silts, sands and gravels are post-Kansan gumbotil erosion, pre-Iowan in age. The Loveland deposits are younger than the valleys cut in the Kansan drift and are overlain in some places by calcareous Iowan till and in other places by unleached gravels of Iowan age."

In the Iowan drift area of northeastern Iowa and in the Illinoian drift area of southeastern Iowa only the loess phase of the Loveland deposits has been found. In the Iowan drift area of northeastern Iowa this loess is post-Kansan gumbotil erosion, pre-Iowan in age. Here the Loveland loess is overlain by calcareous Iowan till. In the Illinoian area of southeastern Iowa the Loveland loess is post-Illinoian gumbotil, pre-Peorian loess in age.

This same relationship of a loess younger than the Illinoian gumbotil and older than Peorian loess was described by Leighton[37] in a paper published in 1926 describing the Farm Creek Section, east of Peoria, Illinois. He interpreted the older loess to be late Sangamon in age. Regional evidence indicates that the reddish or brownish loess older than the widespread Peorian loess in western and southwestern Iowa, Nebraska, northwestern Missouri, and western Illinois is Loveland loess. Figure 13 is a diagrammatic representation of the Loveland loess relationships eastward from the type area in western Iowa.

Loveland Loess

Sections of Loveland Loess

The late Sangamon loess of the Loveland formation has already been described on pages 47 to 50.

The Loveland type section is at the village of Loveland, in sec. 3,

[37] Leighton, M. M., A notable type Pleistocene section: the Farm Creek exposure near Peoria, Illinois: Jour. Geology, vol. 34, pp. 167-174, 1926.

Rockford Township, (T. 77 N., R. 44 W.), Pottawattamie County. Here the following section is exposed:

	Feet	Inches
Peorian intraglacial stage:		
Loess, fossiliferous	75	
Loveland interval:		
Loess, reddish, blocky, vertical joints, pebbly—especially in lower part—calcareous concretions, fossils rare	17	6
Kansan glacial stage:		
Till, oxidized, yellow to chocolate color, breaks into irregular shapes, small lenses of sand included, many calcareous concretions in upper part	11	
Till, chiefly unoxidized and unleached, dark to very dark gray when dry, tough	5	
(Talus)	50	

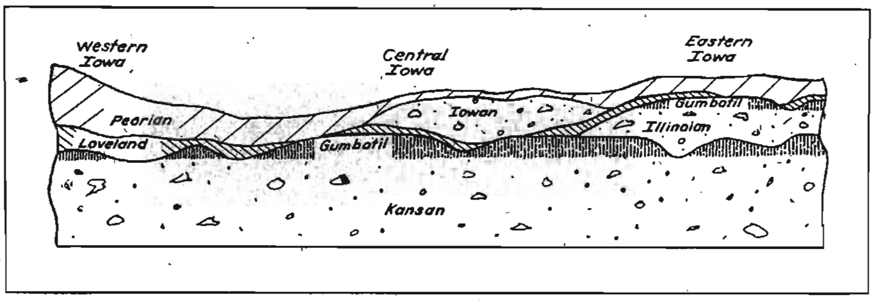

Figure 13. Diagram showing the Loveland loess relationships eastward from the type area in western Iowa.

In the section, it has not been found possible to separate sharply the Loveland loess from overlying Peorian loess, although at several neighboring sections the contact between the two loesses is definite and sharp. Calcareous concretions are well shown in figure 14 which shows a Loveland exposure at Council Bluffs, Iowa.

In a railroad cut in sec. 28, Garfield Township, (T. 72 N., R. 39 W.), Montgomery County, just west of McPherson Station, a fine section of Loveland loess is exposed. The section is:

	Feet	Inches
Peorian intraglacial substage:		
Loess, typical	25	
Loveland interval:		
Loess, concretions in lower part, thoroughly leached, has reddish tinge, pebbles in lower part, some of which are in horizontal bands	20	
Kansan glacial stage:		
Till, oxidized and leached, much red quartzite.		

Just east of McPherson, and but a few hundred yards from the exposure above, the Loveland attains the unusual thickness of 30 feet. It shows the typical reddish joint-clay appearance which in contact with the buff Peorian is quite noticeable. This region is in rolling loess depositional topography with billowy relief and no tabular divides.

Figure 14. Layer of concretions in the Loveland loess exposed in the valley bluffs near Council Bluffs.

Loveland loess is well exposed in a road cut along the NW¼ sec. 32, Henry Township, (T. 91 N., R. 43 W.), Plymouth County. The section is:

	Feet	Inches
Peorian intraglacial substage:		
Loess, unleached, buff, filled with concretions, sandy in the lower part	8	
Loveland interval:		
Loess, leached, carbonaceous; concretions in the upper part, brownish gray. Exposed	3	
Kansan glacial stage:		
Till, unoxidized and unleached, observed below the leached loess 40 rods to the south of the measured section.		

A well known exposure of Loveland loess which has remained available for study for many years is in a bluff just back of the

Third Ward school at Missouri Valley, (T. 78 N., R. 43 W.), in Harrison County. Here the following sequence is seen:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff in color, unleached, highly fossiliferous....	75	
Loveland interval:		
Loess, leached, reddish brown, tends to break with laminations, pebbly in basal part with an occasional pebble in upper part, contact with drift below and loess above is sharp and distinct....	15	
Kansan glacial stage:		
Clay, sandy, yellow, pebbles common, leached....	5	6

A hundred yards north of this section, Kansan oxidized and unleached drift is seen to be overlain by 4 feet of brownish, pebbly Loveland with concretions and some fossils, this seeming to grade upward into typical Peorian loess.

A series of good cuts, also in Harrison County, shows a consistent thickness of about 5 feet of Loveland loess. East from the junction of U. S. highway 30 and State highway 39, the state road cuts through several loess hills between the junction and the county line. On the north side of the road, in the SW¼ sec. 12, Jefferson Township, is the following section:

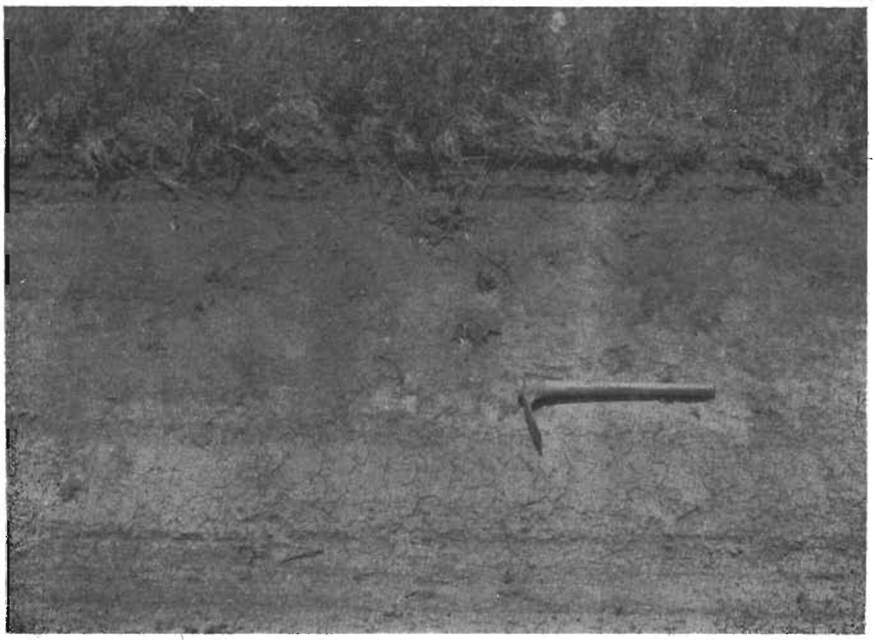

Figure 15. Section showing Loveland loess, Iowan till and Peorian loess. O'Brien County.

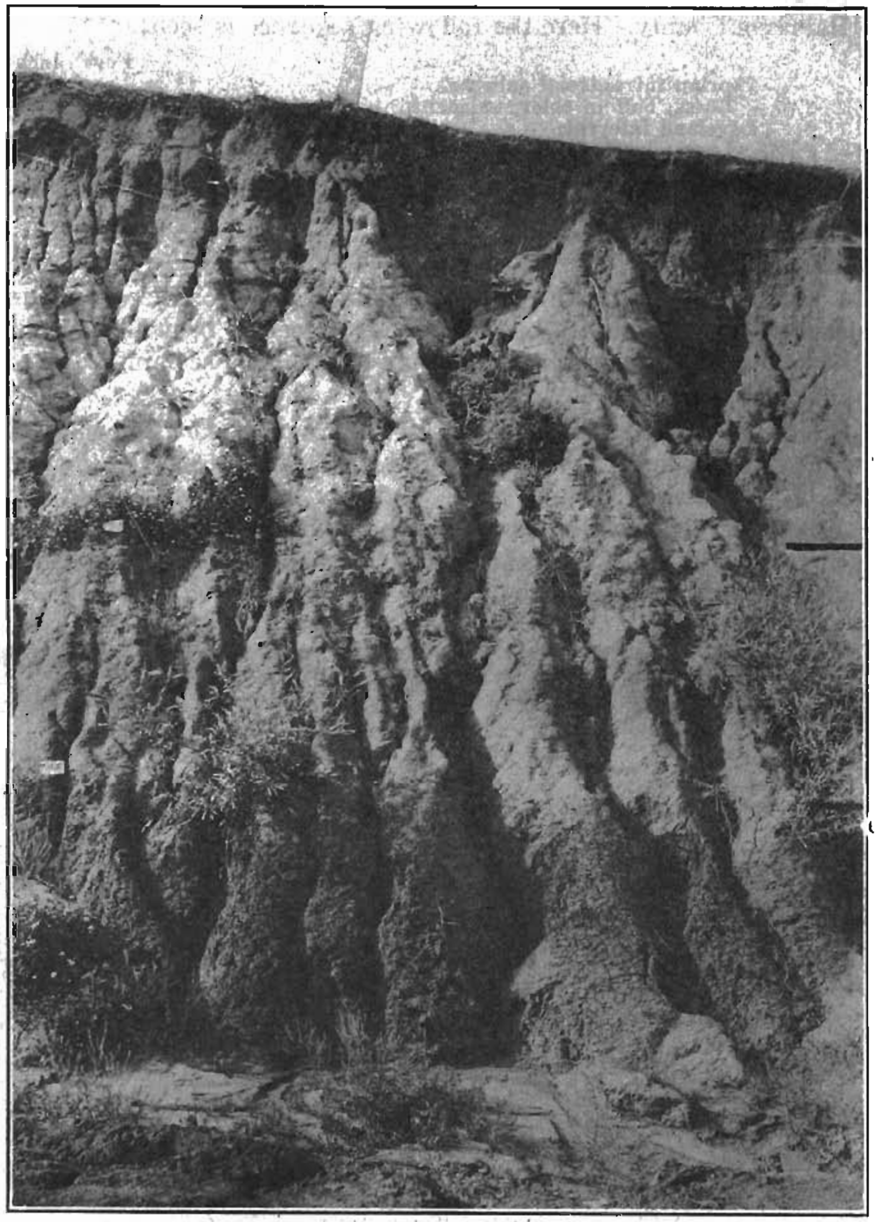

Figure 16. Loveland loess in section in Cass Township, Shelby County.

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, concretions	11	
Loveland interval:		
Loess, distinct reddish tint, more sandy than the Peorian, has concretions, leached	7	

Three more similar sections are seen in the next 3 miles to the east, showing an average of 5 feet of leached Loveland loess below Peorian loess. Below the Loveland in each case is oxidized and leached Kansan till.

In northwestern Iowa, the Loveland loess and the usually overlying Peorian loess is separated by Iowan drift. This relationship is shown along the road between secs. 4 and 9, Carroll Township, (T. 96 N., R. 42 W.), O'Brien County (fig. 15).

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff	1-3	
Iowan glacial substage:		
Till, highly calcareous, pebbly and sandy, oxidized to a yellow-brown color	2-3	
Loveland interval:		
Loess, highly calcareous, plowed into base of till, gray to buff in color	3-5	

The Loveland loess lies on Kansan gumbotil in a cut between secs. 15 and 22, Cass Township, (T. 79 N., R. 40 W.), Shelby County (fig. 16). A section is as follows:

	Feet	Inches
Peorian intraglacial stage:		
Loess, leached, upper part buff in color, grading down into gray loess with iron stains, iron tubules	12	
Loveland interval:		
Loess, leached, brownish gray with numerous brownish-yellow stains, differs distinctly from material above and below	4	
Kansan glacial stage:		
Gumbotil, dark gray to brown, upper part shows considerable secondary calcium carbonate in places, leached. Exposed	3	

The same relationships were seen in a section a few miles east between secs. 16 and 21, Lincoln Township, (T. 79 N., R. 39 W.), Shelby County. In this place the Peorian loess is 7 feet thick, the Loveland is 3 feet thick, and the Kansan gumbotil is exposed for a thickness of 2 feet.

Several sections in northeastern Iowa show the Iowan till overlying the loess phase of the Loveland formation. A section in Fayette County, unusual in its completeness of Pleistocene formations of the area, figure 17, is found along the north line of sec. 16, Windsor Township, (T. 94 N., R. 9 W.). Here the sequence of formations related to the loesses is:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff, mealy, unleached, some concretions, no fossils found	2	
Iowan glacial substage:		
Till, unleached, dark buff on dry surface, yellow brown to brown when damp, cuts readily with hoe, sandy, few concretions	7	

Figure 17. Section in Fayette County, showing Loveland loess below Iowan till.

	Feet	Inches
Sangamon interglacial stage:		
Loess, Loveland, leached, gray with considerable chocolate-colored stain, laminated, putty-like when wet, no pebbles found	2	6
Kansan glacial stage:		
Gumbotil, leached, dark gray on a dry surface, no concretions seen, very few pebbles of any kind—those found all siliceous. Upper 1½ feet contains much carbonaceous matter which shows a distinct soil band through the cut	5	6

Excavations made during the building of the stadium at the University of Iowa, in Iowa City, (T. 79 N., R. 6 W.), Johnson County, gave good exposures of both Loveland and Peorian loesses. The relations are:

	Feet	Inches
Peorian intraglacial substage:		
Loess, buff color, leached to top of slope	10	
Loess, calcareous, buff color, iron tubules, fossil shells	2	
Loess, distinct gray, many iron tubules which show distinctly on the surface of the slope, many fossil shells	8	

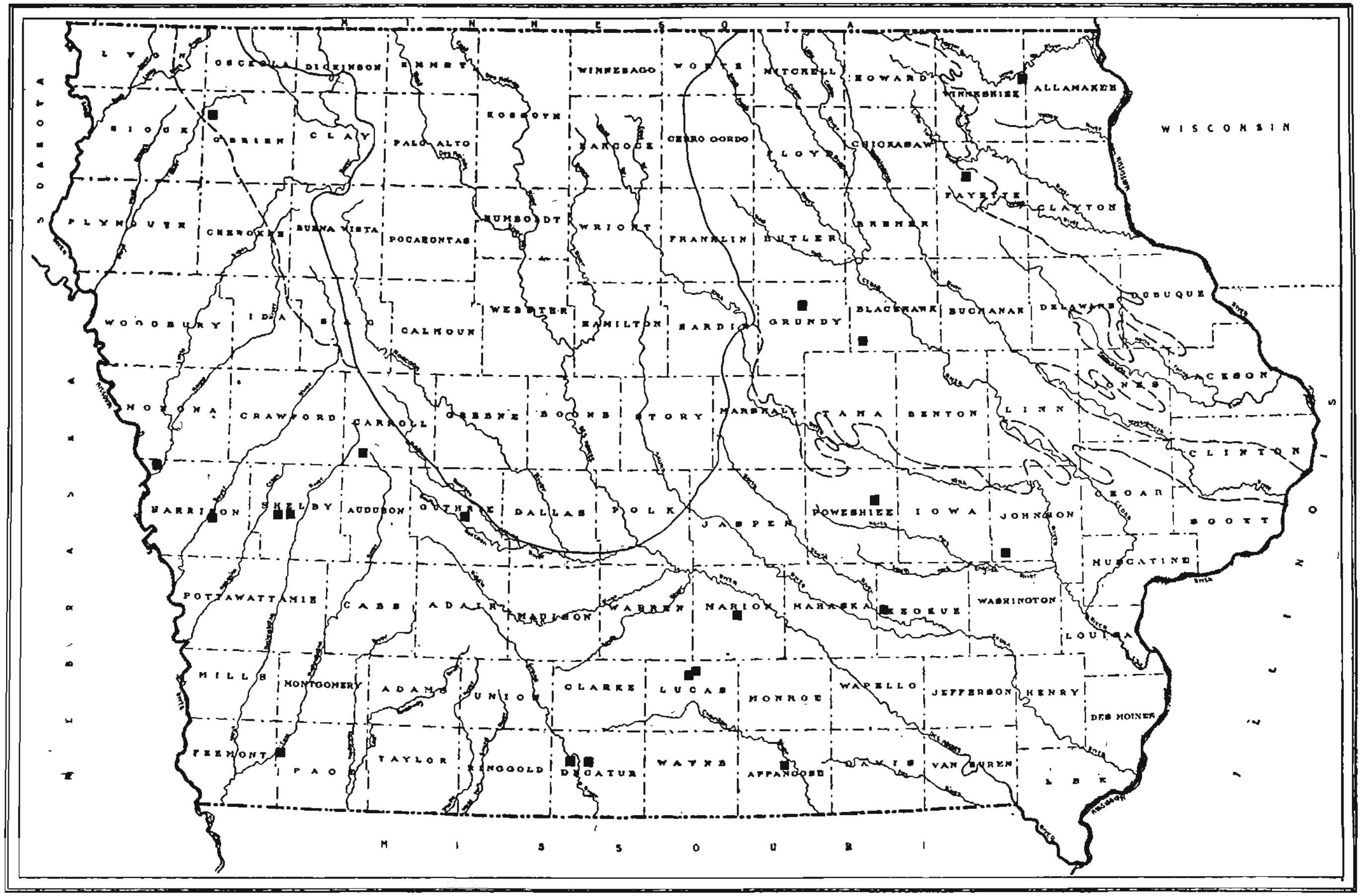

Figure 18. Map showing locations of some Loveland loess samples used in compiling average analyses.

Sangamon interglacial stage:	
Loess, Loveland, leached, oxidized reddish, compact, carbonaceous specks and flakes, distinct from the gumbotil, no pebbles seen	2
Nebraskan glacial stage:	
Gumbotil, drab to dark gray to purplish, mottled dark brown to chocolate, tough, few pebbles, leached, no concretions seen, pebbles are siliceous	6

The Loveland loess is well exposed in this excavation; the contact between the gumbotil and the overlying compact Loveland loess forms a zone of seepage which makes these materials easily discernible. The Loveland averages about 2 feet in thickness over the area and in general appearance is much like the Loveland of western Iowa.

Laboratory Studies of the Loveland Loess

Mechanical Analyses

A total of 35 samples of Loveland loess were collected from widely separated localities over the state, as shown by figure 18, and the materials were subjected to various laboratory analyses by Paul T. Miller. The following size relationships are shown by the mechanical analyses:

The average of the Loveland samples shows a fairly well-balanced distribution of particles both coarser and finer than the maximum size grade percentage, which falls in the 1/16 millimeter to 1/32 millimeter range. This size grade maximum is the coarse silt dimension, and constitutes about 35 percent of the whole. The finest size grade, that of 1/128 millimeter to 1/256 millimeter dimensions, contains 7 percent. The coarsest size grade of significance here is that of 1 millimeter to 1/2 millimeter range, and contains between 1 and 2 percent of the whole. Loveland loess is known to contain sand and pebbles ranging in diameter from 1 millimeter up to 4 millimeters, but the percentage of this coarse material is very small. Figure 19 illustrates the percentage of the various size grades.

Mineral Analyses

Loveland loess rests upon the eroded surface of the Kansan gumbotil over large areas in Iowa. The question arises as to whether the loess was blown into the state from the west and southwest or whether it was derived locally from stream deposits or reworked Kansan drift. The mineral analyses of the Loveland loess correlate closely with the mineral analyses of the Kansan till, which sug-

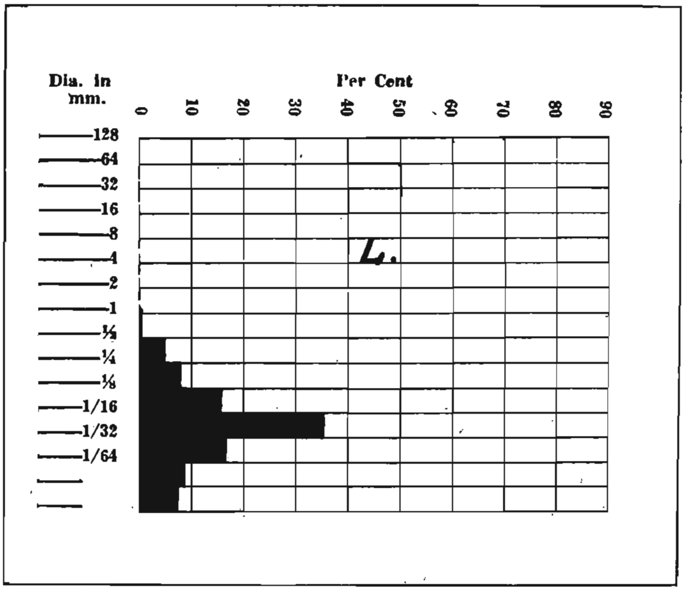

Figure 19. Graph showing mechanical analysis of average of 35 samples of Loveland loess.

gests that the loess in Iowa is of local origin. After the formation of the gumbotil, streams cut through it into the drift and developed wide flood plains. Here fine material could easily have been gathered by the winds and deposited over the surrounding region.

Major constituent minerals of Loveland loess and Kansan till have been determined by Paul Miller as shown in the following tabulation:

Minerals	Kansan till	Loveland loess
Quartz	87.20%	81.30%
Undifferentiated feldspar	9.29	9.82
Microcline	1.74	2.58
Plagioclase (Albite)	1.94	3.32

Minor constituent minerals are:

Minerals	Kansan till	Loveland loess
Pyrite	2.55%	16.40%
Magnetite and Ilmenite	11.12	9.03
Hornblende	38.14	32.36
Pargasite	1.09	1.75
Glaucophane	.42	1.31
Actinolite	.78	1.02
Tremolite	1.09	
Hypersthene	1.81	.72
Enstatite	1.33	.43
Augite	3.45	2.40
Aegerite-Augite	.54	
Aegerite	.54	1.06

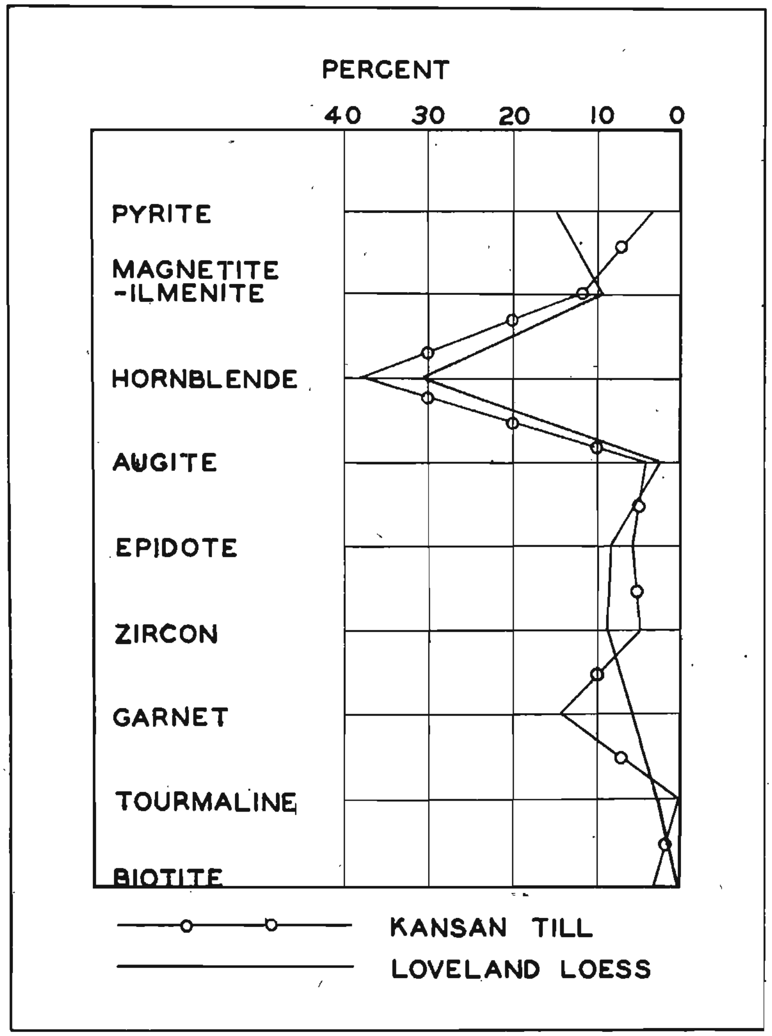

Figure 20. Diagram illustrating similarity of minor mineral percentages in Kansan till and Loveland loess.

Chlorite	1.57	.42
Andalusite		.80
Epidote	7.51	8.76
Zircon	5.55	9.22
Garnet	15.22	5.47
Tourmaline	.49	3.23
Titanite	.78	2.23
Biotite	3.77	.49
Staurolite		.80
Topaz	.18	.27
Kyanite	.73	.27
Rutile	.73	.27
Brookite		.12
Barite	.01	
Monazite	.12	
Riebeckite		.10
Basaltic hornblende	.54	.54
Anthophyllite	.95	.27
Miscellaneous		.26

Figure 20 illustrates the correlation of the most important minor constituent minerals of Kansan till and Loveland loess.

Loveland Sands and Gravels

Sands and gravels of Loveland age are confined largely to several valleys in the western and southern parts of the state as shown in figure 21. The valleys in which sands and gravels have been identified as Loveland in age lie wholly within the loess mantled Kansan erosional drift area. The sources of the sands and gravels must be, therefore, the eroded Kansan drift, the Nebraskan drift, the bedrock, or a combination of these sources.

The occurrence of widespread valley terrace gravels of post-Kansan, pre-Peorian age, the lack of Kansan gumbotil, and the topographic differences between northwestern Iowa and southern Iowa are thought to be the result of uplift in northwestern Iowa which occurred during the Loveland interval. A brief summary of the evidences supporting the view of uplift in northwestern Iowa will clarify the discussion of the relationships of the Loveland gravels which is to follow.

Carman[38] studied thoroughly the Pleistocene geology of northwestern Iowa. In relation to the postulated uplift of that region, Carman states:

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

[38]Carman, J. E., Further studies of the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, pp. 108-111, 1931.

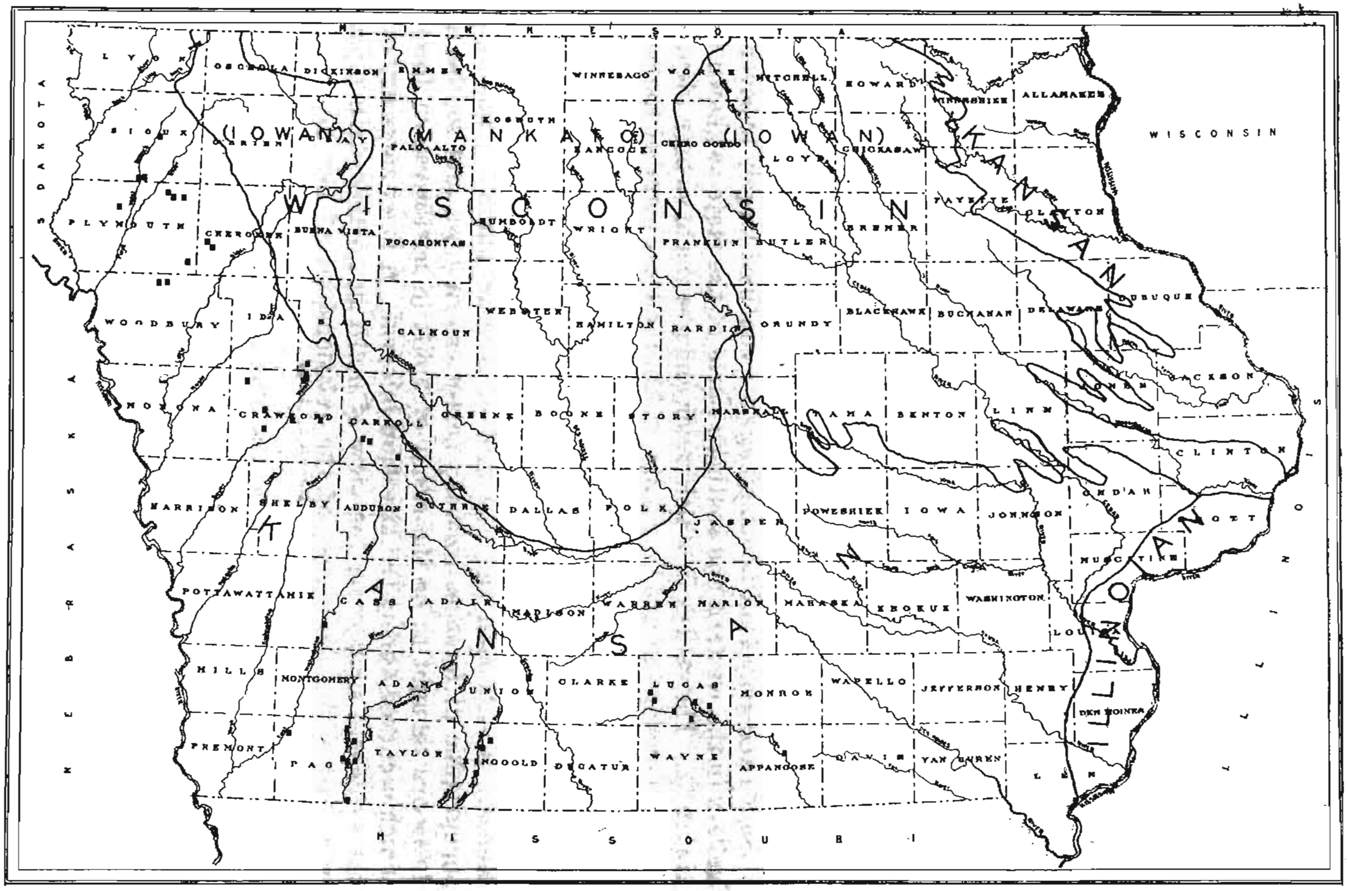

Figure 21. Map showing locations of Loveland sand and gravel exposures in Iowa.

"These level uplands of southern Iowa are covered with about ten feet of gray to dark colored noncalcareous sticky clay which Doctor Kay has named gumbotil and interpreted to be the result, chiefly, of the chemical weathering of Kansan drift on the level Kansan drift plain. After the development of the gumbotil zone an uplift is believed to have occurred, and erosion has carved out a mature topography and reduced most of the surface below the level of the former gumbotil plain. The above interpretation is based on the evidence of the remnants of this plain.

"Remnants of the gumbotil zone are numerous in southern Iowa and continue northward to Carroll and Crawford counties, just south of our region[39] (northwestern Iowa). The most northerly known exposure of the Kansan gumbotil is in a railway cut two miles east of Kiron, a few miles south of the southwest corner of Sac county.

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

"Concerning this matter of erosion of the gumbotil plain in Carroll county just to the south of our area Kay wrote as follows:[40]

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

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

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

[39] Kay, G. F., Pleistocene deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Survey, vol. 26, pp. 213-281, 1917.

[40] Kay, G. F., *op. cit.*, p. 218.

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

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

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

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

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

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

The finding of widespread sands and gravels of Loveland age in western and southern Iowa is in accord with this hypothesis of uplift and erosion in northwestern Iowa. It is probable that all valleys in western and southern Iowa were aggraded to some degree with Loveland sands and gravels. However, Iowan and Mankato glaciation has resulted in valley terracing of the valleys which head in the areas of those drifts, and the differentiation of valley sands and gravels as Loveland in age is possible only in areas which have been unaffected by Wisconsin drainage. Gravels in northwestern Iowa valleys which may have carried Iowan, or Iowan and Mankato glacial drainage, have been designated "undifferentiated terrace gravels" by Kay and Miller[41] and the locations of such gravel deposits are shown on the map in figure 22. Admittedly, these gravels may be in part Loveland gravels.

The most complete field and laboratory study of Loveland sands and gravels has been made by Kay and Miller[42] and the following discussion is based largely on this report.

The Loveland sands and gravels of northwestern Iowa have been altered very little by weathering. They are fresh in appearance. Oxidation has changed the color of the deposits to buff, but nowhere has the deep red color or iron cementation of highly oxidized gravels been observed. The materials are unleached except where the thinness of the loess cover has permitted post-loessial leaching to penetrate into the upper few inches of gravel. There has been little disintegration of the igneous pebbles within the gravels.

The sands and gravels are usually stratified in horizontal beds between 6 and 12 inches thick. The deposits frequently show considerable variation in sorting and in size range. Silts and sands may be interstratified with gravel and cobbles and occasional boulders up to 60 centimeters in diameter may be found in the finer material. The mechanical analyses of average samples from each of several Loveland deposits have been grouped for comparison and are shown in figure 23. The corresponding pebble analyses for the same deposits are shown in figure 24.

There are many exposures of Loveland terrace deposits along the tributary streams of Missouri River, which have their source areas in the eroded Kansan drift region of northwestern Iowa and which have not carried Iowan or Mankato glacial drainage. Deposits of this type occur along Otter Creek, a tributary to Boyer River, in the southwest part of Sac County. A series of gravel pits have been developed along the east side of a valley terrace near the center of the W½ sec. 26, Wheeler Township, (T. 86 N., R. 38 W.), about 5 miles south of the southeast corner of Odebolt. In one pit, a 42-foot section is exposed. The upper 20 feet is typical Peorian loess, leached to a depth of 9 feet, and extending to the sharp gravel contact at its base without variation in texture or color. Below is 22 feet of gravel without a visible contact at the base.

The sand and gravel has been oxidized to a light-buff color, and except for a 2½-foot sand layer at the top, is calcareous throughout. This sand is believed to represent an original lack of calcium carbo-

[41] Kay, G. F., and Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, p. 197, 1941.
[42] Kay, G. F., and Miller, P. T., *op. cit.*, pp. 98-118.

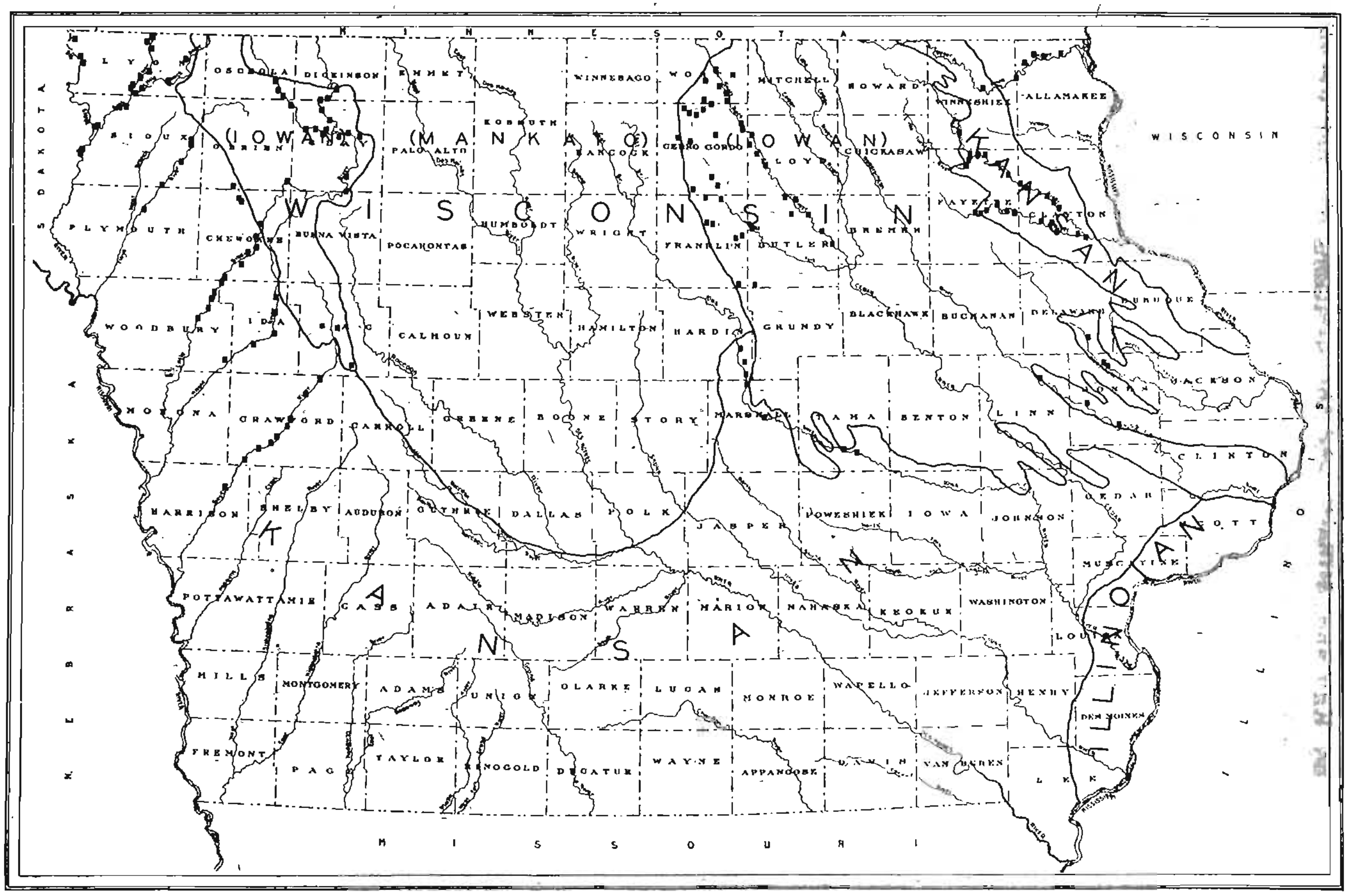

Figure 22. Map showing locations of "undifferentiated terrace gravel" exposures in Iowa.

nate rather than subsequent leaching, as some interstratification of this sand with calcareous gravel lenses has been observed. There has been little disintegration of the igneous rock content of the gravel. Concretions are absent. In size range, the gravel is mostly below 6 centimeters in diameter, although a number of boulders ranging to a diameter of 35 centimeters were found in the bottom of the pit. Seventy percent of the gravel is between 4 millimeters and ¼ millimeter in diameter, as shown in graph no. 1 of figure 23. The gravel is stratified in beds generally about 3 inches thick which dip southeast at an angle of less than 5 degrees. The lithology of the gravel is shown by graph no. 1 in figure 24.

A section along Deep Creek in the south-central part of sec. 31, Meadow Township, (T. 93 N., R. 43 W.), Plymouth County, includes 45 feet or more of Loveland gravels. The top of the gravel is exposed in a terrace 20 feet above the level of Deep Creek. The gravel is overlain by 3 to 4 feet of loess, dark from humus in the upper 18 inches, but light buff below. All of the loess is leached.

The gravel is exposed to a depth of 10 feet, and borings have indicated a total depth of 45 feet or more. The gravel in the upper, exposed portion shows no leaching and has been changed to a light-buff color by oxidation. Disintegration of igneous pebbles is slight. The deposit is well stratified, with strata usually less than 10 inches thick, which dip to the southwest at an angle of about 3 degrees. In size range, a few boulders and cobbles as large as 25 centimeters in diameter have been found, but about 85 percent of the deposit is between 16 and 1/4 millimeters in diameter. The mechanical and lithological analyses of an average of the gravel from this exposure is given in graph no. 4 in figures 23 and 24.

On Brushy Fork, a tributary of South Raccoon River, Loveland gravels are exposed in the central part of sec. 20, Newton Township, (T. 82 N., R. 34 W.), Carroll County, in the southwest corner of Dedham.

Here leaching has removed the carbonates from 4 feet of loess overburdened and from the upper 6 inches of gravel. The gravel is a slightly darker buff color than the sections described earlier. Pebble disintegration has been slight. The gravel is well stratified, with cross bedding common within the major beds. Texturally, about 50 percent of the gravel is between 1 and 1/4 millimeters in diameter. With the exception of a few large boulders which have a maximum diameter of 30 centimeters, none of the gravel measured

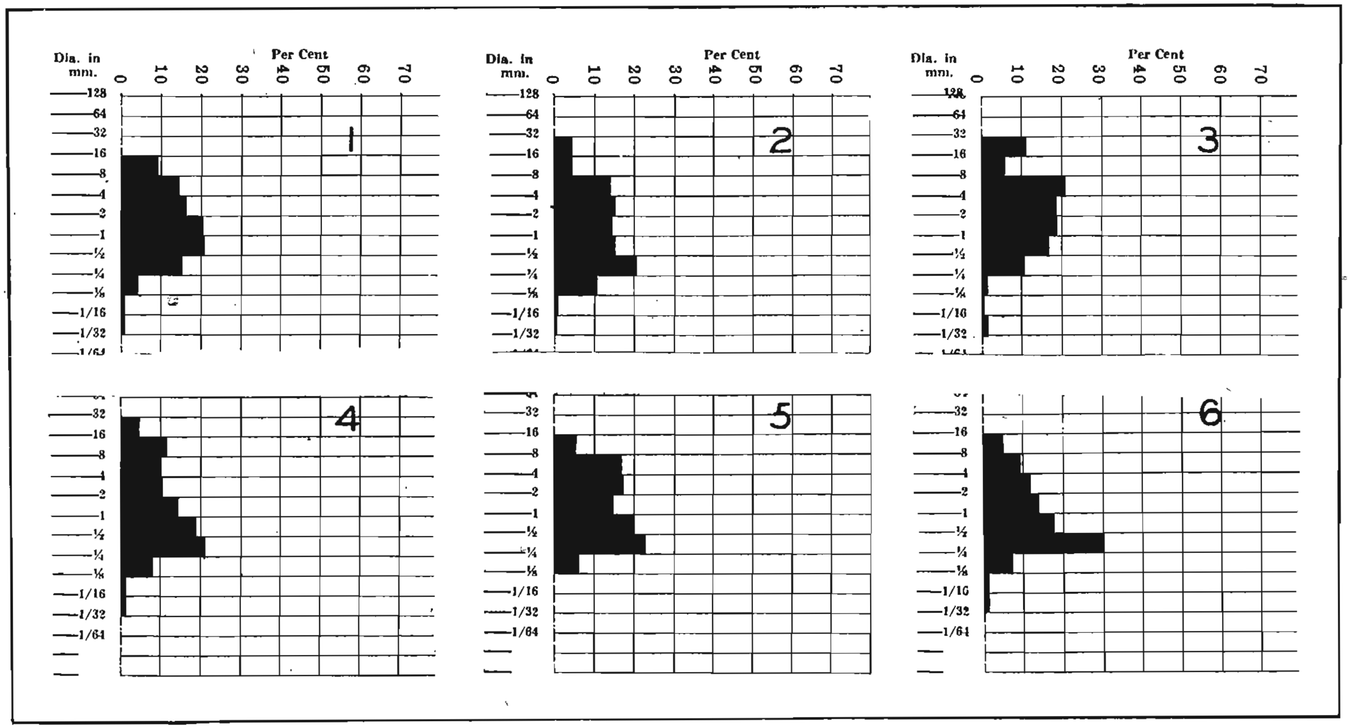

Figure 23. Graphs showing mechanical analyses of Loveland gravel. The numbers of this figure correspond with those of figure 24.

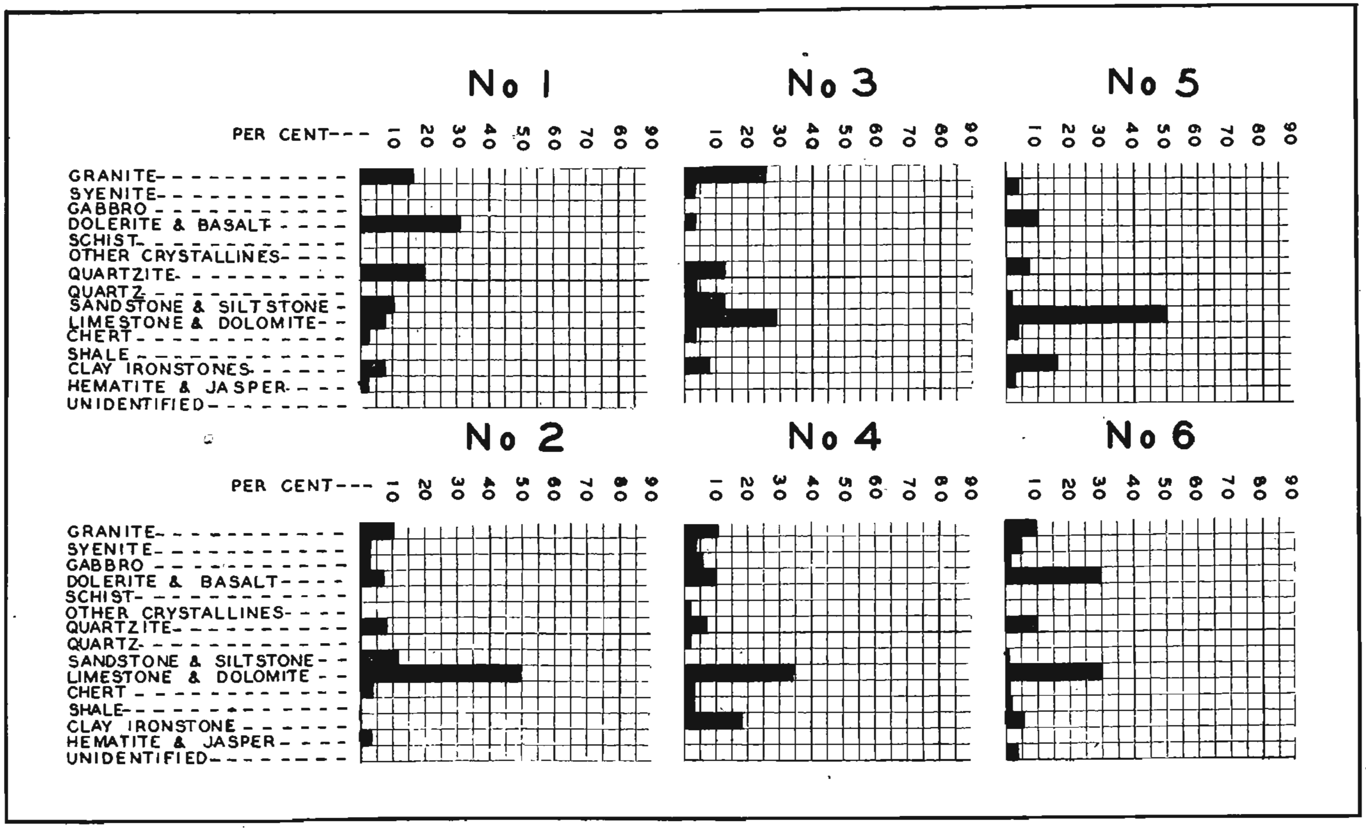

Figure 24. Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond to those of figure 23.

more than 5 centimeters in diameter. The mechanical analysis of an average sample is shown by graph no. 6 of figure 23, while the lithology of the gravel is represented by graph no. 6 of figure 24.

The Loveland sands and gravels of southern Iowa differ in several respects from the gravels of northwestern Iowa which have just been described. Younger loess and alluvium obscure the Loveland deposits in most places as the Loveland silts, sands and gravels are situated low in the valley walls and in many places the streams have not cut deeply enough to expose them. That the presence of these materials has long been recognized, is apparent from the work of Calvin.[43] However, he did not give them the same interpretation which has subsequently been determined for them, as the formational nature of materials in the present Loveland formation had not been worked out at that early date.

About 3 miles east of Clarinda, Loveland silt, sand and gravel is exposed in a dredged ditch along the East Nodaway River, in the SW¼ sec. 34, Nebraska Township, (T. 69 N., R. 36 W.), Page County. The section is:

	Feet	Inches
Post-Loveland time:		
Alluvium, black, silty clay, unstratified, tough and heavy, unleached	10	
Loveland interval:		
Loess, gray-brown mottled, unstratifed, leached	4	
Silt, gray, stratified, grades into loess above, beds thin, laminations at the top, but toward the base the beds become thicker and the material coarser, including sand and some gravel, all leached	3	
Gravel, gray, sandy, leached, poorly stratified in relatively horizontal beds; exposed		4

Several exposures of Loveland deposits in Lucas County have been observed. One of these is along a branch of White Breast Creek, near the center of sec. 21,, Benton Township, (T. 71 N. R. 21 W.). This entire section is leached of its carbonates. The section is:

	Feet	Inches
Loveland interval:		
Soil filled with roots	2	
Sand, gray; and gravel, oxidized, brownish and reddish, strongly cemented	3	
Sandy clay band		6
Gravel, oxidized, brownish yellow	1	9
Clay seam, distinct		2
Sand, white	1	
Sand, yellow, pebbly below	1	
Clay seam		2
Sand, white with yellow streaks, oxidized at base	1	
Kansan glacial stage:		
Till, yellowish gray	8	

[43]Calvin, Samuel, Geology of Page County: Iowa Geol. Survey, vol. 11, pp. 444-447, 1901.

If there is any Peorian loess here, it is very thin.

A comparison of the Loveland sands and gravels in northwestern Iowa with those in southern Iowa seems to indicate a difference not only in weathering but in type of material. It is probable that the terrace gravels described in northwestern Iowa were deposited fairly late in the Loveland interval, and that they are made up largely of materials that had undergone but little weathering. In southern Iowa, the more advanced oxidation and leaching of most exposures seems to indicate that those materials were deposited earlier in the Loveland interval than were the gravels of northwestern Iowa. Furthermore, the Loveland streams in southern Iowa probably contained a much higher percentage of weathered material than did the contemporaneous streams in northwestern Iowa, which were supplied for the most part by the relatively rapid erosion of unleached Kansan drift.

As yet, it has not been possible to establish accurately the chronology of Loveland deposits within the long Loveland interval. While it is true that some deposits, by virtue of their stage of weathering, can be said to be younger or older than other similar deposits, Loveland sands and gravels cannot be given a Sangamon, Illinoian, or late Kansan age with any certainty. Additional investigation of the Loveland formation as a unit may reveal that less inclusive age determinations are possible for these Loveland sands and gravels.

Volcanic Ash in the Loveland Formation

Volcanic ash or pumicite occurs in the Loveland formation in western Iowa, eastern Nebraska, and eastern South Dakota. In Iowa, the volcanic material has not been found in thicknesses exceeding 3 feet, but in Nebraska the ash is, in places, 3 to 8 feet thick, and southwest of Eustice, Frontier County, it is 50 feet thick in places.[44]

The ash is in the lower part of a loess phase of the Loveland formation, or may be associated with Loveland silts and clays showing deposition in water, but changing gradually into the typical eolian loess phase of the overlying Loveland. Frequently, sections of the Loveland which include the volcanic ash indicate that the pumicite was deposited in shallow ponds, lakes or bayous after the sands and gravels of the Loveland age had been deposited. In Iowa, this history is indicated by numerous exposures along Sioux River north of the town of Little Sioux, Little Sioux Township, Harrison County.

[44]Lugn, A. L., The Pleistocene geology of Nebraska: Nebraska Geol. Survey, Bull. 10, pp. 132-134, 1935.

Figure 25a. Volcanic ash in the Loveland formation. Harrison County.

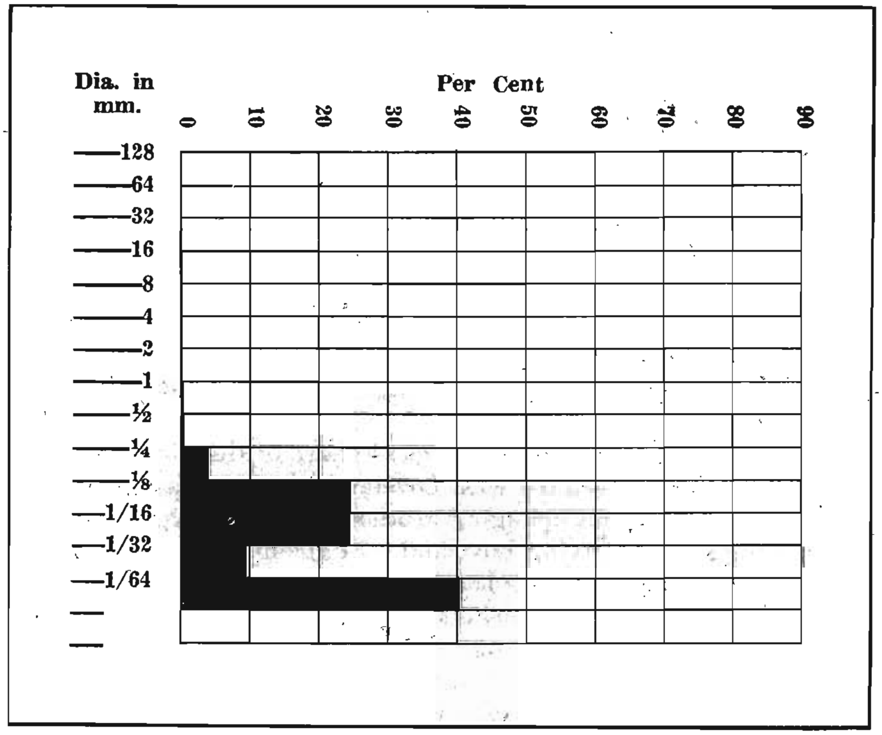

Figure 25b. Graph showing mechanical analysis of Loveland volcanic ash from Harrison County. (After A. C. Tester.)

Here Sioux River, after entering the valley of Missouri River just north of the Monona-Harrison County line, flows close against the east valley wall north of Little Sioux, and has cut a sharp bluff which rises from the flood plains of Sioux and Missouri Rivers. Gravel pits in the base of this bluff have exposed several good sections of the Loveland formation.

A section of a loess phase which includes the ash is at the so-called County-line exposure, along the north line of sec. 5, Little Sioux Township, (T. 81 N., R. 45 W.), Harrison County. The section follows:

	Feet	Inches
Loveland interval:		
Loess-like clay, brown to yellow in color, concretions, no fossils seen, occasional small pebble. Not sharply separated from the ash below.		
Volcanic ash, exposed along the slope for 25 feet, thinning at the ends	3	
Loess brown to gray to yellow color, mostly brown in upper part which breaks like joint clay, no fossils seen, concretions, occasional small pebbles, some effervescence with acid	3	
Sand, base unexposed.		

The pumicite layer of this section is shown in figure 25a. About 100 yards south of this exposure the ash overlies gravels. The ash here is somewhat higher than in the section just described.

Only a few yards removed from these two locations, a cut shows oxidized and unleached sands and gravels stained in streaks and lenses with manganese dioxide grading upward into sandy gray silt. The silt is fossiliferous in the upper part. Above the silt occurs a 2-foot bed of volcanic ash, light in weight in the lower half, but grading upward into a silty, laminated clay. The ash is distinct in its whiteness and light weight. There is no apparent depositional break in sedimentation either above or below the ash.

Several exposures of the ash in this general region clearly show interbedding of the ash and a silty basal phase of the Loveland loess. The relation of the ash to the overlying loess is distinct.

Mechanical and mineralogical analyses have been made of the Loveland volcanic ash by Tester.[45] Ash from the County-line exposure referred to above consists of the percentages of size grades, shown in figure 25b when mechanically analyzed. The 1/2-1/4 millimeter size grade consists almost entirely of very angular glass fragments, a small number of rounded detrital quartz grains and about 10 percent of kaolinitic aggregates. The glass and the aggregates are

[45]Tester, A. C., Personal communication.

spotted with iron oxide stains. The 1/4-1/8 millimeter size grade consists of fragmental glass, about 3 percent of kaolinitic aggregates, and a few rounded to subrounded detrital quartz grains. The glass and the aggregates are spotted with stains of iron oxide. The 1/8-1/16 millimeter size grade consists of glass in fragments and stringers, practically no aggregates, some detrital quartz grains that show some rounding. Iron stains are also present. The 1/16-1/32 millimeter size grade consists of fragmental glass, a very small number of detrital quartz grains and aggregates, all of which are iron stained. The 1/32-1/64 millimeter size grade has the appearance of the preceding grades with a decrease in the number of aggregates and detrital quartz.

The particles of ash can be classified into four main groups. These types are as follows:

1. Fragments of glass that once inclosed the bubble walls.
2. Y-shaped fragments formed where a number of bubbles were close together.
3. Flat, triangular-shaped plates of glass broken from the walls of large vesicular cavities.
4. Elongate fragments having a fibrous structure.

The mineral content of the ash other than the volcanic glass consists of iron oxide, pyrite, biotite, garnet, quartz and aggregates of weathered aluminum silicate.

CHAPTER III

THE ELDORAN EPOCH (SERIES)
THE WISCONSIN GLACIAL AGE (STAGE)

The Iowan Glacial Subage (Substage)
The Peorian Intraglacial Subage (Substage)
The Mankato Glacial Subage (Substage)

THE CLASSIFICATION OF THE WISCONSIN AGE (STAGE)

The name East Wisconsin was first used by Chamberlin[46] in 1894 for the most recent of the glacial ages of the Pleistocene period. The following year at the suggestion of Upham the name was shortened to Wisconsin.[47] Soon two substages, early Wisconsin and late Wisconsin, were recognized. More recently Leverett[48] described three substages, early, middle and late Wisconsin. The early Wisconsin drift was interpreted to have come from the Labradorean center, the Middle Wisconsin from the Patrician center, and the Late Wisconsin from the Keewatin center. Then in 1931, as a result of detailed field studies in Illinois, Leighton[49] proposed a modification of the use of the name Wisconsin in Pleistocene classification. The change involved the elimination of the Peorian as an interglacial stage and the inclusion of the Iowan stage as the oldest substage of the Wisconsin. The evidence in Illinois had convinced Leighton and his associates that there was continuous deposition of loess, previously interpreted to belong to the Peorian interglacial age, from Iowan time until after early Wisconsin time; and furthermore, that the interval heretofore called Peorian was so short as to necessitate its elimination as an interglacial age from the classification of the Pleistocene. Moreover, Leighton proposed that since the Iowan glacial age cannot longer be recognized in Pleistocene classification as being independent in age from Wisconsin age, the usage of the name Wisconsin of our present classification be modified to include the Iowan as the earliest of its substages. He proposed also that the Wisconsin substages be named, from oldest to youngest, Manitoban (Iowan), Quebecan (Early and Middle Wisconsin), and Hudsonian (Late Wisconsin). Later he realized that the terms herein used were not appropriate, partly because they re-

[46]Chamberlin, T. C., in James Geikie, The great ice age, pp. 753-764, 1894.
[47]Chamberlin, T. C., The classification of American glacial deposits: Jour. Geology, vol. 3, pp. 270-277, 1895.
[48]Leverett, Frank, Moraines and shorelines of the Lake Superior region: U. S. Geol. Survey Prof. Paper 154-A, 1929.
[49]Leighton, M. M. The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley: Jour. Geology, vol. 38, pp. 45-53, 1931.

ferred to fields of ice accumulation rather than areas where the drift deposits might be studied, and partly because they were preempted. Leighton[50] therefore proposed other names to replace the names, Manitoban, Quebecan, and Hudsonian, for the substages of the Wisconsin. They are, from oldest to youngest, the Iowan, the Tazewell (Early Wisconsin), the Cary (Middle Wisconsin), and the Mankato (Late Wisconsin).

After Kay had had an opportunity to study Leighton's field evidence in Illinois, he agreed with him that the relationships of the Peorian loess to the Iowan and the Early Wisconsin justified the inclusion of the Iowan in the Wisconsin stage as redefined in the preceding paragraph. Kay and Leighton,[51] being in agreement with regard to the relationships of the Iowan to the Wisconsin, published a paper together entitled "The Eldoran Epoch of the Pleistocene Period." In this paper, the previous classification of Kay's Eldoran epoch was revised for the Mississippi Valley as follows:

Epoch (series)	Age (stage)	Substage
	Recent	
Eldoran	Wisconsin	Mankato (Late Wisconsin) Cary (Middle Wisconsin) Tazewell (Early Wisconsin) Iowan

In Iowa, only the Iowan and Mankato substages of the Wisconsin are present. Separating the Iowan drift from the Mankato drift is the Peorian loess which is related closely in age to the Iowan. The name Peorian in Iowa is now used for the widespread loess which lies on the Iowan drift and around its borders, and beneath the Mankato drift. The Peorian is no longer an interglacial stage but an intraglacial substage. The present classification of the Wisconsin age (stage) in Iowa is as follows:

Epoch (series)	Age (stage)	Subage (substage)
Eldoran	Recent	
	Wisconsin	Mankato Peorian Iowan

[50]Leighton, M. M., The naming of the subdivisions of the Wisconsin glacial age: Science, new ser., vol. 77, p. 168, 1933.
[51]Kay, G. F., and Leighton, M. M., The Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-673, 1933.

THE IOWAN GLACIAL SUBAGE (SUBSTAGE)

Discrimination of the Iowan drift
Distribution of the Iowan drift in Iowa
Origin of the Iowan drift
Changes in the Iowan drift
Typical sections of the Iowan drift
  Iowan drift in northeastern Iowa
  Iowan drift in northwestern Iowa
Descriptions of the drift phases
  Iowan boulders
  The Iowan pebble band
  Oxidized and leached Iowan till
  Oxidized and unleached Iowan till
  Unoxidized and unleached Iowan till
Iowan gravels
  Iowan upland gravel
  Iowan terrace gravel
Thickness of the Iowan drift

Discrimination of the Iowan Drift

For many years the Iowan drift has been the subject of much controversy. At times, its very existence has been questioned and much discussion has taken place as to its relationships. By some geologists, the Iowan has been interpreted to be closely related in age to the Illinoian drift, and other geologists have contended that the Iowan drift is much younger than the Illinoian drift and is closely related to the Wisconsin drift.

Since some geologists are not yet convinced that the "Iowan problem" has been solved, it would seem desirable to present at this time a brief history of present day viewpoints. Much of this history has been presented in papers already published.[52]

Previous to 1880 McGee had found evidence of two tills in northeastern Iowa, and in 1881 he[53] referred to them as the Upper Till and the Lower Till, each having its own distinctive characteristics. In some places his Upper Till was the surface till and in other places the Lower Till was at the surface. He was able to map both the tills areally. Where both tills were present in a section they were separated, in many places, by a forest bed or its stratigraphic equivalent, "hardpan" or "gumbo," which he stated was the modified upper portion of his Lower Till. At this time, McGee interpret-

[52]Kay, G. F., Pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, pp. 70-134, 1929.
Kay, G. F., The relative ages of the Iowan and Illinoian drift sheets: Am. Jour. Sci., 5th ser., vol. 16, pp. 497-518, 1928.
Kay, G. F., The relative ages of the Iowan and Wisconsin drift sheets: Am. Jour. Sci., 5th ser., vol. 20, pp. 158-172, 1931.
Kay, G. F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 425-466, 1931.
Kay, G. F., Pleistocene history and early man in America: Geol. Soc. America Bull., vol. 50, pp. 453-464, 1939.
[53]McGee, W J. The relations between geology and agriculture: Iowa Horticultural Soc. Trans., 16, pp. 227-240, 1881.

ed the widespread loess of northeastern Iowa as being equivalent in age to his Upper Till. In his final report on northeastern Iowa, based upon investigations which extended over many years, McGee[54] described in detail the topographic and lithologic character, the stratigraphic relations, and the geographic extent of his Upper Till and his Lower Till. He pointed out that his Upper Till was younger than the gumbo-surfaced drift (present Kansan drift) of southern Iowa, and older than the till of the Des Moines lobe (present Wisconsin drift). McGee did not differentiate in northeastern Iowa a third drift (present Nebraskan drift) which has no mappable surface distribution within his area but which has been exposed in a few places within his area, in railroad cuts and in road cuts, and has been penetrated in well drillings.

The name East Iowan was applied to McGee's Upper Till after Chamberlin[55] had given this name to the younger of two tills at Afton Junction. In explanation of the term East Iowan he stated on page 760, that "the designation East Iowan Formation is chosen because it has been most carefully worked out by Mr. McGee in northeastern Iowa and there displays its most distinctive features." The name was later shortened to Iowan. Calvin and his associates studied in detail and mapped with little difficulty the Iowan till (Upper Till) in many counties in McGee's area.[56]

In the year 1899 Calvin[57] published a paper in which he described fully the features of the Iowan drift which differentiate it from the other drift sheets of the Mississippi Valley. The paper refers to many aspects of the Iowan, including (1) the origin of the name Iowan; (2) the area occupied by the Iowan drift sheet; (3) the characteristics of the Iowan drift—the topography, color and composition of the till, its boulders, etc.; (4) relation of the Iowan to the "Forest Bed" of northeastern Iowa; (5) comparison of the Iowan with the Kansan, the Illinoian and the Wisconsin tills; and (6) the Iowan margin, including a discussion of its sinuosities and digitations, the loess ridges along its margin, etc.

By the beginning of the present century there was general agreement among the geologists who had studied in Iowa and adjacent states that the evidence justified the interpretation that Pleistocene history had been long and complex, embracing five glacial and four

[54]McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey 11th Ann. Rept., pp. 195-568, 1891.
[55]Chamberlin, T. C., in James Geikie, The great ice age, pp. 753-764, 1894.
[56]Kay, G. F., and Apfel, E. T., Pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, footnote, p. 78, 1929.
[57]Calvin, Samuel, The Iowan drift: Geol. Soc. America Bull., vol. 10, pp. 107-120, 1899.

interglacial ages, each of which had been described and named. The recognized classification was as follows:

Wisconsin
    Peorian
Iowan
    Sangamon
Illinoian
    Yarmouth
Kansan
    Aftonian
Pre-Kansan

The Iowan drift sheet was interpreted at this time to be related closely in age to the Wisconsin drift sheet, and the widespread loess was called Iowan loess because of its relationship in origin and in age to the Iowan drift. It was at about this time that the loess was being interpreted as eolian rather than fluvio-glacial in origin. Soon the loess, on account of the fossils it contains, was interpreted to be not contemporaneous with the Iowan drift but somewhat later in age than the Iowan. With this change in interpretation the loess began to be called the Peorian loess. It had been deposited in the short interglacial age between the Iowan and Wisconsin glacial ages.

The published record shows clearly that at this time—about the year 1900—this classification had the approval of all the students of glacial and interglacial deposits of the Mississippi Valley—the classic area.

A few years later, the reality of Iowan drift began to be questioned. Leverett,[58] in a paper in which he discussed the application of weathering and erosion to the correlation of drifts, expressed the view that the topography of the Iowan area in northeastern Iowa was of the erosional type such as characterizes the Kansan drift but that in northeastern Iowa tabular divides were lacking and none of the drift was fresh. He believed that filling of the valleys by slope wash in the Iowan area accounted for the differences in topography of this area and that of the Kansan of southern Iowa. Leverett's skepticism of the Iowan followed field study in the Iowan area, one of the objects of which study was to determine whether or not the Iowan drift was in reality Illinoian drift from the Keewatin field. He concluded that the surface material was not different from the weathered Kansan drift and that if any post-Kansan drift was present, it was probably of Illinoian age. In a later paper, Leverett,[59]

[58]Leverett, Frank, Weathering and erosion as time measures: Am. Jour. Sci., vol. 27, pp. 349-368, 1909.

[59]Leverett, Frank, Comparison of North American and European glacial deposits: Zeitsch. Gletscherkunde, B. 4, pp. 241-285, 321-342, 1910.

in referring to the Iowan drift, used the expression "so-called Iowan of the Keewatin field (Illinoian)."

Two main questions have been at the center of attacks on the Iowan: (1) Is there an Iowan drift? and, (2) Does the Iowan drift belong to the Illinoian glacial stage?

After the death of Calvin in 1911 it seemed highly desirable to have a review of the evidence bearing upon the Iowan problem and hence, with the hope that a satisfactory solution to the question in controversy might be reached, George F. Kay, Calvin's successor as State Geologist of Iowa, asked the United States Geological Survey to undertake the investigation in cooperation with the Iowa Geological Survey. It was agreed that W. C. Alden of the Federal Survey should be assisted by M. M. Leighton of the Iowa Survey. Field work was carried forward during two seasons and in the office careful study was given to published and unpublished material related to the Iowan problem. The results of the investigations of Alden and Leighton were published in Volume 26 of the Annual Reports of the Iowa Geological Survey.[60] In the Introduction to this report, page 56, it is stated:

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

The reasons for their judgment are presented fully in this paper. In connection with the discussion of the age of the Iowan drift, Alden and Leighton presented evidence for their belief that the Iowan drift is a distinct drift from the Illinoian drift. They stated:

> "From these various observations it is evident that the Illinoian drift has been modified much more by weathering and erosion than has the Iowan. It also appears that most of the modification occurred prior to the formation of the main deposit of loess. It appears clear therefore that the Iowan drift is entirely distinct from and considerably younger than the Illinoian drift."

In 1923 Leverett, in a letter written to T. C. Chamberlin, W. C. Alden, M. M. Leighton, and G. F. Kay, with regard to an appropriate name to be given to the loess overlying the Iowan and Illinoian tills, stated: "I still regard the occurrence of a drift such as outlined by Calvin (i. e., Iowan drift) as unsettled." Since Leverett had not been in northeastern Iowa for several years prior to the

[60]Alden, W. C., and Leighton, M. M., The Iowan drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, vol. 26, pp. 49-212, 1917.

time this statement was made, and hence had not seen the strong evidence in favor of the Iowan drift which had been made available for study in the many road cuts and other exposures which were made in connection with the new road grading within the Iowan area, Kay invited Leverett to accompany him into northeastern Iowa in the summer of 1925. He accepted the invitation and together they examined some of the most significant exposures within the Iowan area. Paul MacClintock, then of the University of Chicago, and Kay's assistant, E. T. Apfel, accompanied them. Agreement of interpretation was reached on all important matters with the exception of the significance of the pebble band on the Iowan till. Leverett contended that the pebble band was the result chiefly of erosion by running water and that much time had been involved in its formation. He favored the view that the till on which the pebble band had been formed was the result of an ice sheet from the Keewatin field and equivalent in age to a late phase of the Illinoian drift. He was of the opinion that the time between the retreat of the ice from the Iowan area and the deposition of the overlying loess was comparable to the time between the retreat of the Illinoian ice from southeastern Iowa and the deposition of the loess overlying the Illinoian drift, which loess is of the same age as that overlying the Iowan drift. He would make the Iowan drift the product of a late phase of the Illinoian stage of glaciation and would give the name Sangamon to the interval between the Iowan drift and the overlying loess as well as to the interval between the Illinoian drift and the loess which overlies it.

As a result of evidence seen and discussed during this field conference; Leverett did not again question the existence of a post-Kansan drift in northeastern Iowa, but the age of the drift continued to be a subject of difference of interpretation. The evidence which had been published by Calvin, and later by Alden and Leighton, was emphasized in support of the view that the Iowan drift is young in comparison with the Illinoian and hence should be retained as a separate glacial stage in Pleistocene classification. Moreover, it was pointed out by Kay that the strongest argument in support of the Iowan drift being younger than the Illinoian drift is the presence over wide areas in southeastern Iowa and Illinois of from 3 to 4 feet of Illinoian gumbotil on the Illinoian till and beneath the Peorian loess, whereas in the Iowa area the Iowan till is leached only to a depth of a few feet and is so young comparatively that gumbotil has not yet been developed anywhere on this till, not even where the topographic position of the Iowan till is very similar to the topographic position of the Illinoian till, e. g., on the uplands.

The interpretation of Leverett as expressed by him in the field conference in 1925 was presented in 1926 in a paper read before the American Philosophical Society in Philadelphia.[61] A part of this paper deals with "the Iowan drift of northeastern Iowa and its probable correlatives." This part of Leverett's paper called forth a reply by Kay.[62] From this paper the following quotations are made:

"Before presenting his reasons for favoring the correlation of the Iowan drift with the Illinoian drift Leverett states: 'If it is granted that the Iowan drift stands for a glacial stage between the Illinoian and Wisconsin stages there were five glacial stages in America.' The vital question then is, is the evidence which is favorable to the correlation of the Iowan with the Illinoian of sufficient weight to offset the strong evidence in support of the Iowan and Illinoian being considered as independent stages?

"Mr. Leverett in his paper calls to the reader's attention the fact that for some time after the Iowan drift was differentiated from the Kansan drift in northeastern Iowa the opinion prevailed that the widespread loess of the area was aqueous in origin and was of the same age as the Iowan. However, in this connection it should not be forgotten that as early as 1904 the view that was accepted quite generally in Iowa was that the loess is not aqueous but is eolian in origin. From that time to the present it has been the judgment of all persons connected with the Iowa Geological Survey, and others, that the loess is not Iowan in age but was deposited a comparatively short time after the retreat of the Iowan ice. This was the view of Calvin in the later years of his life, and the view which was advanced by Alden and Leighton in their report on the Iowan drift in the 1915 Annual Report of the Iowa Geological Survey.

"It is to the interpretation that the loess overlying the Iowan till was deposited but a short time after the retreat of the Iowan ice sheet that Leverett takes exception. It is here that he finds his chief basis for suggesting the correlation of the Iowan till with the Illinoian till. He emphasized the significance of the pebble band which separates the Iowan till from the overlying loess. The pebble band which was seen by Leverett, MacClintock, Apfel and the writer in the summer of 1925 is described in his paper in some detail. Here he states the judgments which he expressed in the field conference to which reference has already been made. He believes that the pebble band is the result of slope wash rather than of wind action. He thinks that a great length of time was necessary for the development of this pebble band, and hence the loess overlying the pebble band must be very much younger than the Iowan till upon which the pebble band lies.

"Leverett states in his paper that the Iowan drift 'lies wholly within the limits of what has been termed the Keewatin field of glaciation.' And then after having presented some facts with regard to the growth of ice sheets, particularly with reference to the Wisconsin, he applies the same principles to the method of growth of the Illinoian. He states 'It seems but natural that westward growth such as we know affected the Wisconsin ice sheet should also have occurred in the Illinoian stage and given the ice movement that brought in the Iowan drift.' Here we have his theoretical grounds for thinking that the Iowan drift should be correlated with the Illinoian.

"Mr. Leverett gives but brief consideration to the evidence that has been presented by Calvin, Alden and Leighton, the writer, and others in support of the interpretation that the Iowan and Illinoian glacial stages were widely separated in age. He attempts briefly to explain the lack of gumbotil on the

[61]Leverett, Frank, The Pleistocene glacial stages: Were there more than four?: Am. Phil. Soc. Proc., vol. 65, no. 2, 1926.

[62]Kay, G. F., The relative ages of the Iowan and Illinoian drift sheets: Am. Jour. Sci., vol. 16, pp. 511-514, 1928.

Iowan and in places on the Kansan. The absence of gumbotil on the Iowan could be explained, he believes, by the lack of summit flats. In this connection it should be stated that some parts of the Iowan area have the same topographic position and character as the upland flats of the Illinoian area upon which the gumbotil is found. His reference to lack of gumbotil on the Kansan in northwestern Iowa is without significance since he failed to recognize that the writer and others have presented field evidence to warrant the interpretation that gumbotil was developed on the Kansan till in that area, and that in connection with the development of the present topography in that area the gumbotil was eroded, leaving the oxidized and unleached Kansan till with much secondary calcium carbonate at the surface.[63]

"In closing his discussion of the Iowan in relation to the Illinoian Leverett states:

" 'In view of all the features of the Iowan drift, taken in connection with the fact that it stands as the third drift of the western district, as the Illinoian does of the eastern, and that each district has but four drifts, the writer raises the question whether there really were more than four Pleistocene glacial stages in North America, or whether the Iowan drift should be regarded as a late phase of the third glacial stage. Features of the Iowan drift and its relation to the loess seem to demand further critical field study.'

"It must be kept clearly in mind that Leverett now is suggesting four glacial stages instead of five, not because he questions the existence of the Iowan drift as he did until recently, but for the reason that he believes the Iowan drift may be a late phase of the Illinoian and hence should be correlated with that drift sheet. The task therefore is no longer that of proving whether or not there is an Iowan drift, but of showing even more definitely than has been done thus far the relations of the Iowan drift to the Illinoian drift."

Kay pointed out in his paper that the chief arguments against the correlation of the Iowan with the Illinoian are (1) the occurrence of gumbotil on the Illinoian till in contrast with no gumbotil on the Iowan till even within those parts of the Iowan area which have the same topographic position and character as the upland flats of the Illinoian area upon which the gumbotil is found; and (2) the presence of two loesses on the Illinoian drift whereas there is only one loess on the Iowan, this loess on the Iowan being the widespread Peorian loess, the younger of the two loesses on the Illinoian. Evidence was presented to support the interpretation that the Peorian loess was deposited very soon after the retreat of the Iowan ice sheet but a long time after the retreat of the Illinoian ice sheet. This interval between the time of deposition of the Illinoian till and the time of deposition of the Peorian loess was of sufficient duration to account for (a) the formation of a gumbotil more than 3 feet thick by the weathering of unoxidized and unleached Illinoian till; (b) the deposition of a loess, the older loess, on the gumbotil and on the eroded surfaces of the Illinoian till; and (c) the leaching of this older loess in places to a depth of several feet.

[63]Kay, G. F., Pleistocene deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Survey, vol. 26, pp. 218-219, 1917.
Carman, J. E., Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol 35, pp. 108-111, 1931.

The "Iowan problem" continued to occupy the central place among discussions of the Pleistocene of the Mississippi Valley. Leverett[64] in 1930, in his retiring address as Vice-President of Section E, Geology and Geography, of the American Association for the Advancement of Science, made the following statement:

"The Iowan, or third drift of the region west of the Driftless Area of the Upper Mississippi Valley, is of such a problematical character that the students who have examined it have been unable thus far to come to an agreement as to its place and rank in the glacial series . . . . . The principal question now in dispute is the relation of the Iowan to the Illinoian drift. Chamberlin and Leverett in recent years have referred it tentatively to the same glacial stage as the Illinoian drift. But Kay and his associates on the Iowa Geological Survey and Alden of the U. S. Geological Survey hold to an early idea that it is the product of a distinct glacial stage standing between the Illinoian and Wisconsin. They grant, however, that there does not seen to be any equivalent of the Iowan drift in the district east of the Mississippi Valley. They thus restrict the Illinoian drift to the Labrador part of the Laurentide field of glaciation, and the Iowan to the Keewatin part, which seems a very doubtful and unnatural restriction.

"The reference of the Iowan drift to a later glacial stage than the Illinoian is based by these students on the lack of a gumbotil deposit on its surface, such as is found on neighboring parts of the Illinoian drift. They also maintain that the erosion and weathering and especially the leaching of lime is less on the Iowan drift. Recently Kay has announced the presence of a loess deposit on the Illinoian drift that seems to him to correlate with a loess that underlies the Iowan drift. The absence of gumbotil on the Iowan drift seems to be due to a lack of favorable conditions for its development rather than to a lack of time. It is hoped that further field study may clear up the remaining points of difference."

In a later paper Leverett[65] states:

"An early interpretation that the Iowan is a distinct glacial stage falling between the Illinoian and Wisconsin glacial stages is still stoutly adhered to by several glacialists, but the present writer and also T. C. Chamberlin have expressed the view that the Iowan may stand as the western or Keewatin phase of the same glacial stage as the Illinoian and have a similar relation to it that the Late Wisconsin drift has to the Early Wisconsin."

In these two papers, Leverett's correlation of the Iowan with the Illinoian seems to be based to a greater extent on theoretical grounds rather than upon field evidence.

In 1939, Leverett's latest paper[66] dealing with the Iowan problem appeared in the Journal of Geology. It is entitled "The Place of the Iowan Drift." In this paper he refers to a statement which he had made in a report published in 1932.[67] The statement is as follows:

"The Iowan drift is so scanty and its limits in northeastern Iowa, as well as in southeastern Minnesota, are so ill-defined, that its extent is still an

[64] Leverett, Frank, Problems of the glacialist: Science, new ser., vol. 57, 1930.
[65] Leverett, Frank, Relative length of Pleistocene glacial and interglacial stages: Science, new ser. vol. 72, p. 194, 1930.
[66] Leverett, Frank, The place of the Iowan drift: Jour. Geology, vol. 47, pp. 398-407, 1939.
[67] Leverett, Frank, and Sardeson, F. W., Quaternary geology of Minnesota and parts of adjacent states: U. S. Geol. Survey Prof. Paper 161, p. 28, 1932.

open question. There seems also to be an entire absence of recessional moraines. These conditions strongly suggest a stagnation or nearly complete cessation of movement in the Iowan ice sheet soon after it had reached its culmination position. The belts of gravelly ridges, which generally have a trend toward the border of the drift instead of parallel with it, are consistent with and seem to support the interpretation of a stagnation of ice movement'."

On page 35 of the same report the following statement appears in reference to the part of the Iowan drift exposed west of the Des Moines lobe of late Wisconsin drift:

"Although the Iowan drift in this district west of the Des Moines lobe of Wisconsin drift has a more definite border than that east of this lobe, it seems to have no recessional moraines and is generally a very scanty deposit. These conditions make it seem probable that this part of the Iowan ice sheet also became stagnant soon after reaching its culminating position."

His generalization with regard to the statement just made is as follows:

"For the consideration of glacial students I am now presenting the view that a condition of stagnation in an ice sheet is more natural for a waning or dying-out phase of a glacial stage than would be natural for the opening phase of a glacial stage. If the Iowan is a late phase of the Illinoian glacial stage, as I have maintained in my latest report, there seems nothing surprising to have it reach a stagnant condition. But, if it comes as the opening phase of the Wisconsin glacial stage, it seems to me unnatural for it to become stagnant."

In this paper he presents field evidence from Minnesota and Wisconsin and states that he "believes that the matter under discussion can be better worked out in Minnesota and Wisconsin than in Iowa," and suggests that those areas be carefully studied before final judgments are reached as to the relationships of the Iowan drift.

Leverett further states:

"A few words seem appropriate on the efforts of certain glacial students to give finality to the intrepretation that the Iowan drift is an early Wisconsin product and to practically exclude the alternative interpretation referring it to the Illinoian glacial stage. This is particularly unfortunate since it may be reproduced in textbooks and books intended for the general reader."

". . . If then in Table 1 the names in parentheses, added by the writer, were used, this slight addition might make a presentation of the alternative classification unnecessary."

TABLE I

Wisconsin glacial	Mankato drift (late Wisconsin) Cary drift (middle Wisconsin) Tazewell loess Tazewell drift (early Wisconsin) Iowan loess Iowan drift (possibly Illinoian)
Sangamon interglacial	
Illinoian glacial (perhaps including the Iowan drift)	
Yarmouth interglacial	
Kansan glacial	
Aftonian interglacial	
Nebraskan glacial	

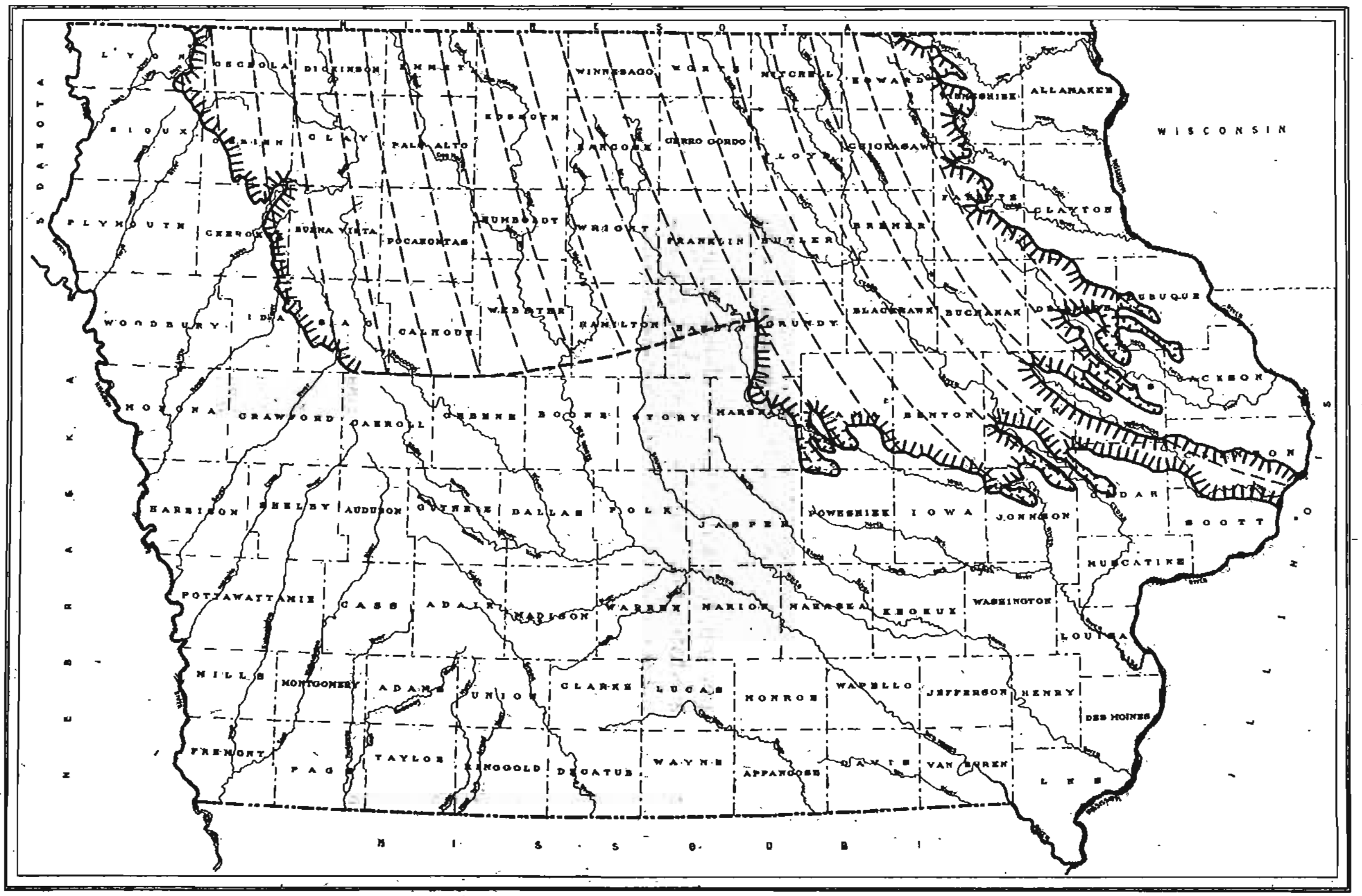

Figure 26. Map of Iowa showing the extent of Iowan glaciation in the state.

By way of summary, it perhaps should be stated that a study of the records shows that of the several geologists who have studied the Iowan drift in the field in Iowa and adjacent areas, Leverett is the only geologist in recent years who has been maintaining that the Iowan is closely related to the Illinoian. Other geologists have presented evidence to show that the Iowan is more closely related to the Wisconsin than the Illinoian, and Kay and Leighton, as has already been stated, have included the Iowan as the oldest substage of the Wisconsin stage.*

Distribution of the Iowan Drift in Iowa

The characteristic topography of the Iowan drift makes its presence in an area quite readily determinable. The uneroded portions of the Kansan drift plain remain as flat, tabular areas. The uneroded Iowan plain is in many places gently rolling but elsewhere, for example in Mitchell and Worth counties and adjacent Iowan areas, the topography shows as flat, level upland surfaces as are presented in places by the Kansan and Mankato upland plains.

The valleys of the Iowan drift region also have a characteristic appearance. In contrast with the steep walls of the gullies and many of the larger valleys of the Kansan area the Iowan valleys present gentle slopes, except where they are rockbound, and many of them grade almost indefinably into the drift plain.

The Iowan drift originally had a surface distribution nearly across northern Iowa (fig. 26). It was by far the most extensive in Iowa of the three later drift sheets and it spread out within one or two counties of the bounding rivers on both east and west margins of the state. It probably entirely covered about 25 counties and occupied parts of 20 others. But the latest advance of the Wisconsin ice, the Mankato, (fig. 76), in its extension down the valley of Des Moines River, covered nearly one-half of the Iowan drift sheet and left at the surface the Iowan area including more than 20 counties on its eastern side, and a much smaller roughly triangular area extending from southern Sac County northward into Minnesota on its western side. This western area has been so thoroughly described by Carman[68] that little can be added here. Carman states that:

"It is believed that before the deposition of the Iowan drift this region had an erosional topography developed on the Kansan drift plain. . . . These pre-

*While this paper was in press, Leverett stated in the Journal of Geology, vol. 50, November-December, 1942, "The Iowan drift of Iowa and Minnesota I now regard as a Keewatin product of Early Wisconsin rather than of Late Illinoian age."

[68]Carman, J. E., Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, pp. 39-48, 1931.

Iowan features were not completely obliterated by the Iowan drift sheet and still remain as the greater relief features of the region. Upon these larger features the Iowan drift sheet superposed a glacial topography with minor constructional features making uneven billowy slopes."

Carman is here writing of the area west of the Mankato lobe of the Wisconsin drift sheet. Because of the probable fact that northwestern Iowa was elevated somewhat more than were other parts of the state after the development of the Kansan gumbotil, it may be that the Kansan drift plain in this region had been eroded nearer to a peneplane before the coming of the Iowan ice than had the Kansan plain elsewhere. This would tend to make the surface of the Iowan drift somewhat smoother in western Iowa than in the eastern area.

A remarkable feature of the southeastern margin of the Iowan drift sheet is the series of lobes or prolongations that extend out from the general front, in some cases for many miles. These appear to be parallel with the main line of the ice advance; that is, they stretch southeastwardly from the main drift sheet. A few small but well-defined lobes are present in Winneshiek and Fayette counties, but the largest are found from Dubuque to Johnson counties, with a shorter series in Tama and Marshall counties. Several features are worthy of mention. Those parts of the margin that are parallel to the direction of ice movement, as the border across parts of Fayette, Clayton and Delaware counties and that across Benton County, are free from lobes. The lobes do not occupy the valleys but either lie on the uplands or extend across upland and valley indiscriminately. These lobes can hardly be erosion remnants, both because of their form and position and because of the comparative freedom from erosion of the Iowan drift.

Another unusual feature of the Iowan drift area is the presence of a number of inliers or islands of Kansan drift here and there over the Iowan plain. These islands show typical rugged Kansan topography, are heavily loess-covered and usually stand above the surrounding Iowan plain. They seem to be indicative of the thinness of the Iowan drift and also to suggest that the Iowan ice was not very strongly erosive as it crossed the Kansan plain of northern Iowa.

The Iowan drift is not everywhere a thin veneer on the Kansan erosional surface. In places, the Iowan displays constructional features having a thickness up to 60 feet as measured from neighboring Kansan gumbotil levels. Thin loess may or may not cover these mounds of drift, but when present it does not constitute an appreciable part of the thickness.

The whole assemblage of features of the Iowan drift plain indicates that its topography is constructional rather than erosional, that it still retains the features impressed on it by the erosional topography of the underlying Kansan drift and by the ice sheet that brought it down and laid it over the Kansan surface.

A good deal of the margin of the eastern area of the Iowan drift can not be located exactly because it is concealed by the thick layer of loess that is piled on it. Inward from the margin this loess is thin, in most counties not over 1 or 2 feet in thickness, although in a few localities its thickness may reach 4 or 5 feet. Outward from the margin the thickness is much greater, reaching 50 feet or more in some places near the edge. However, it thins rather abruptly outward and within a few miles is only a few feet thick.

In the Kay and Apfel report is a map[69] showing by patterns the main areas of distinct topographic development in Iowa. On this map the Iowan areas are named the "eastern area of drift mantled erosional topography" and the "western area of drift mantled erosional topography" (fig. 27). With regard to the eastern area, the following statement on page 51 is made:

"The eastern Iowan area occupies the greater part of the northeastern quarter of the state. The area includes all or parts of twenty-five counties as is shown in figure 26. It is roughly quadrilateral in shape.

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

"From a topographic standpoint this area is more typically 'gently rolling' than any other part of the state, and there is no distinct topographic datum plane to which the relief can be related as in southern Iowa. The river valleys are in most places fairly broad in relation to the streams in them, and instead of these broad valleys having wide flood-plains, many of them have concave profiles. Some writers have stated that the streams flow in 'sags' which extend for miles along the stream courses, the sags being best explained as partly filled broad valleys. The flood-plains in some places at least are not built of alluvial materials, but are drift flats appearing now probably much as they did when the ice-sheet left them.

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

"In parts of this drift mantled area the relief is very slight, and the surface for mile after mile appears to the eye to be almost level. All parts are drained, however; no lakes exist, but small ponds are formed in depressions during heavy or prolonged rainfall, and formerly extensive areas were boggy during wet seasons. The slight relief which is characteristic of these

[69]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, p. 37, 1928.

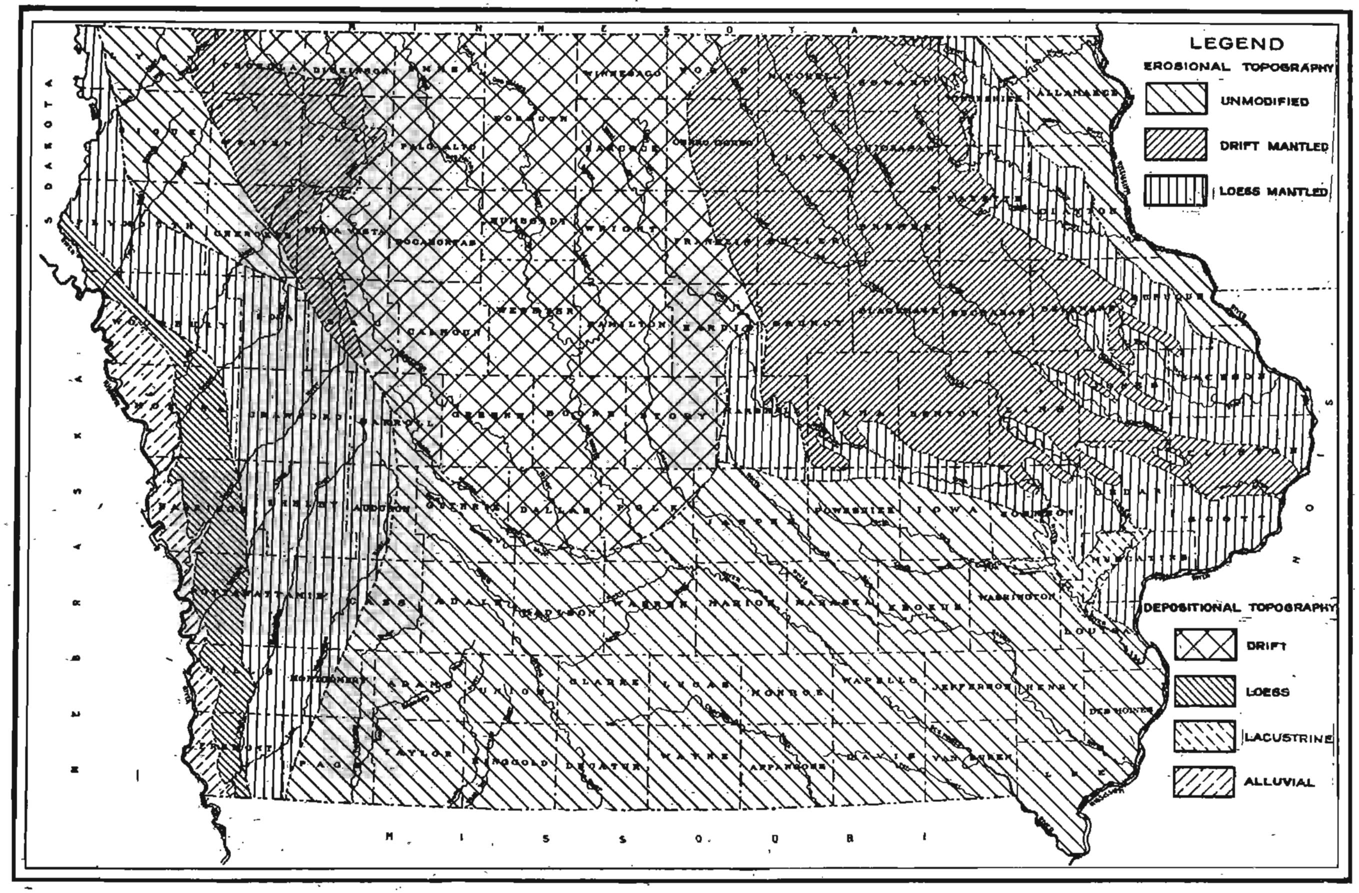

Figure 27. Map of Iowa showing by patterns the main areas of distinctive topographic development in the state.

flat areas cannot be explained satisfactorily as being the result of erosional agencies alone, but rather as having been made by the deposition of material distributed irregularly over broad tabular divides remaining on an erosional surface. The broadly concave valleys the inconspicuous divides, and the swells on drained level stretches indicate a depositional modification of a normal erosional surface. In accord with this interpretation is the presence of numerous immense boulders and many boulders of less size which are not distributed in relation to major drainage lines, but which occur with little relation to the topography.

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

The statement by Kay and Apfel on page 53 with regard to the northwestern area is as follows:

"The northwestern Iowan area of drift mantled erosional topography includes nine counties; it is about twice as long as it is wide, with the long axis extending a little east of south from the Minnesota line, as shown in figure 26. The east boundary is strongly bowed eastward following the edge of the Wisconsin drift, whereas the west boundary is bowed slightly to the west. The drift in this area, as in the eastern drift mantled erosional area, is Iowan drift lying on an eroded Kansan drift surface.

"The northwestern area differs from the northeastern area in that the drift mantle in the northwestern area was deposited on a surface which had been reduced by erosion not only to a mature stage but to a stage well advanced toward old age. Such a surface has less conspicuous relief than a mature erosional surface and when covered by a mantle the new surface is likely to obscure more of the characteristics of the underlying erosional surface than in a region where the drift mantle is deposited on a mature erosional topography. The more the underlying erosional features are obscured the more apparent are the effects of the mantle. In the northwestern Iowan area the valleys and their tributaries do not have the distinctive dendritic drainage features characteristic of topographies due to erosion only. In places the valley walls have been sharpened or smoothed, in other places spurs due to deposition extend into valleys, and in places there is morainal topography.

This western area of Iowan drift is covered by several feet of loess, derived largely from the valley of Missouri River to the west. The loess thins to the eastward, and extends beneath the Mankato drift.

Origin of the Iowan Drift

The Iowan drift has several distinctive features. It contrasts markedly with other Pleistocene drift sheets in the sinuosities of its till border, its thinness, its distribution in interstream areas and about islands of Kansan topography, its loess relationships, and its burden of enormous, prominently granitic erratics. It is young enough to have escaped, thus far, noticeable stream dissection. Time has been too short for the formation of a gumbotil upon the uneroded uplands and leaching has progressed downward for an average depth of not more than 5½ feet. One must therefore ascribe such differences as are observed in the comparison of the Iowan drift with other Pleistocene drift sheets of Iowa, to original differences.

The load acquired by continental glaciers is a composite of all surface debris and mantle rock which the glacier is able to incorporate by freezing into its mass, by plucking, gouging, and shoving ahead of the ice front. In addition, bedrock is frequently scoured to depths below previous depths of surface weathering, and fresh country rock is added to the load. Thus, the drift material of any glacier is a resultant of all the materials, both of the surface and the bedrock, of the whole of the area invaded by the ice. In the case of the Iowan drift in Iowa, much of the till deposited is without question of previous glacial origin, having been deposited within, or north of the state, as part of older tills. Since this is true, it might be expected that the Iowan till would noticeably reflect the weathering of that part of its glacial content which was surface material during the Sangamon interval just previous, or for longer periods of time. However, below the depth to which post-Iowan leaching has taken place, Iowan till is comparable in lime content to the unleached portions of older tills, and like the Illinoian, which moved across the aging surfaces of the Nebraskan and Kansan drift, is on the whole a fresh drift.

That part of the Iowan glacier which invaded the northern half of Iowa is related to the Keewatin center of glaciation, and entered the state almost directly from the north. The prevalent granite erratics are of northern stock, as there is no possible source of such material within the boundaries of Iowa. Early describers of this drift remarked about the predominance of the lighter granitic types over the higher greenstone content of older drifts, particularly the Kansan.

Perhaps those very features of unusual mobility and thinness of the Iowan ice may explain the unusual size and number of erratics, due to the comparative inability to grind to pieces and digest great units of resistant rock.

Whatever may be the conditions which effected the distinctive features of the Iowan drift, the drift materials themselves indicate the heterogeneous sources common to all continental glaciers. These materials have been mixed together and redeposited as the gravelly till, the boulder fields, and the gravel and outwash areas of the Iowan drift.

Changes in the Iowan Drift

With the retreat of the Iowan ice from the area it occupied in Iowa, certain changes in the physical and chemical character of the freshly exposed till occurred, produced chiefly by the weathering agencies of oxidation and solution. It is apparent from observations along road cuts through fresh unoxidized and unleached till, that the process of oxidation takes effect immediately upon exposure of a fresh surface, and penetrates with a speed relative to the many chemical and physical factors inherent in the material and surrounding local environment. Thus, the first apparent change in the till would be the yellowish-brown stain of iron oxide which would creep downward into the till with diminishing speed, as the compactness of the deeper till and the surficial oxidation reduced the effectiveness of the process.

Equally quick to begin modifying the till character is the process of solution of the normally high percentage of calcium carbonate in the till. However, this is a much slower process than that of oxidation, and since the retreat of the Iowan ice, removal of the lime content in the till has occurred generally only in the upper 5½ feet. The penetration of the process of oxidation outstrips that of leaching, such that the normal sequence seen in the Iowan till is as follows:

Iowan oxidized and leached till
Iowan oxidized and unleached till
Iowan unoxidized and unleached till

The depth of leaching on the Iowan, as well as on the Mankato till, is graphically illustrated in figure 28.

The Iowan till lacks the gumbotil phase which has been found on the three older tills. This lack is quite in accord with all evidence pointing to the formation of gumbotil as an extreme product of the same weathering processes described above. With sufficient time, a gumbotil would presumably be formed on the uneroded Iowan surface by continued chemical and physical changes taking place in the already leached and oxidized surficial materials of the Iowan drift.

Typical Sections of the Iowan Drift

Iowan Drift in Northeastern Iowa

The Iowan drift of northeastern Iowa everywhere lies within the area covered by Kansan drift, with the possibile exception of a narrow overlap of Iowan on Illinoian in northern Scott County. As

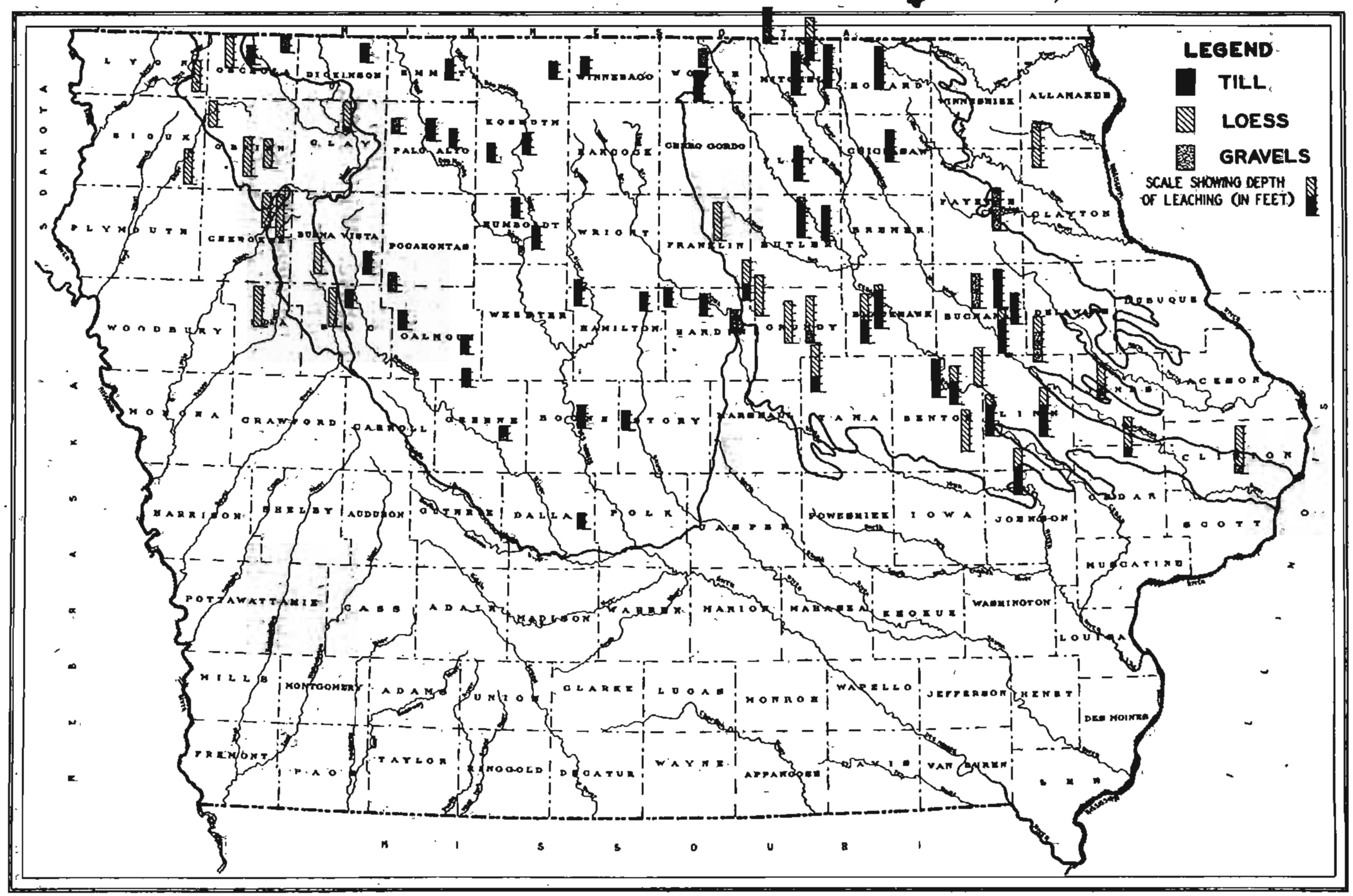

Figure 28. Map of Iowa showing by diagram the depths of leaching of calcium carbonate in materials within the Iowan and Mankato drift areas of Iowa.

a matter of fact, however, the Iowan drift is known to lie on the indurated bedrock or its weathered derivatives, on various phases of Nebraskan drift, on Aftonian deposits, on the different types of Kansan till and gravels, and on the Loveland loess and other kinds of deposits of Buchanan age.

Some examples of Iowan drift lying on bedrock are to be seen in sec. 20, Union Township, (T. 87 N., R. 4 W.), Delaware County, where a rocky knoll projects through the drift; and 3 miles south of Manchester, in the same county, where a group of blocks of Niagaran limestone rises above the drift plain. Iowan till was found lying on Nebraskan gumbotil 2 miles north of Manchester, in the NE¼ sec. 17, Delaware Township, (T. 89 N., R. 5 W.). The road cut here showed:

	Feet	Inches
Iowan glacial substage:		
Till, oxidized, dark yellow, pebbly; upper part loamy, leached	3-5	
Nebraskan glacial stage:		
Gumbotil, gray, leached, siliceous pebbles; exposed	1	

The gumbotil is determined to be Nebraskan by its elevation, which is 985 feet, while Kansan gumbotil not far away is 1042 feet above sea level. The topography surrounding this cut is distinctly Iowan. One-fourth mile south of this cut a pit showed 11 feet of chocolate-colored leached gravels resting on limestone. This gravel lies at the same elevation as the Nebraskan gumbotil and is considered to be of the same age.

One of the best known sections in northeastern Iowa is the cut at Oelwein, (T. 91 N., R. 9 W.), Fayette County, on the Chicago Great Western Railway. This has been visited by many geologists, and it has been described by Kay and Apfel,[70] and by others. Before slumping it showed Iowan till, Buchanan sand and gravel, Kansan till, Aftonian sand underlain by peat, and Nebraskan till. Some geologists have questioned the reality of the Iowan in this section. It has even been called "graders' dump". But Kay has recently been able to verify the accuracy of the assignment of the upper beds to the Iowan. He was able to make out the following strata in the upper part of the cut, on the south side, where no graders' dump is present:

	Feet	Inches
Iowan glacial substage:		
Soil, dark, loamy		6
Till, brownish to yellowish, fairly compact, leached	5	
Till, oxidized, unleached. Thickness not determinable on account of vegetation on the slope.		

[70]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, pp. 199-200, 1929.

On the north side a similar section was found *beneath the graders' dump*. The distinctive Iowan boulder-bearing topography is present to the edges of the cut.

Another very good section was revealed in grading U. S. highway 18 along the north line of sec. 16, Windsor Township, (T. 94 N., R. 9 W.), also in Fayette County. This too was described by Kay and Apfel, on page 230 of the report just cited. It shows a somewhat different succession, including loess and Iowan till, both unleached; Loveland loess, leached; Kansan gumbotil and till, leached. This cut is in the marginal moraine and the hills to the south rise 37 feet above the gumbotil. This is an unusual thickness of Iowan, one rarely found except near the margin.

A section in the middle of the NE¼ sec. 4, Lincoln Township, (T. 98 N., R. 20 W.), Worth County, shows a very complete series of Pleistocene deposits within an unusually short vertical range. The section includes:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	½-1	6
Iowan glacial substage:		
Till, yellow, sandy and pebbly, leached	1-2	
Sangamon interglacial stage:		
Loess, gray with brown patches, no pebbles, somewhat sticky, starchy texture, leached. Cuts more easily than does underlying bed and is lighter gray		2
Kansan glacial stage:		
Gumbotil, hard, dark gray, compact, distinctly starchy texture	3-4	
Till, oxidized, leached, brown, dense; transition from bed above abrupt; exposed	1	

Another section that shows a more nearly normal thickness of Iowan materials is a road cut in the SW¼ sec. 3, Polk Township, (T. 86 N., R. 9 W.), Benton County. The north side of this cut shows:

	Feet	Inches
Peorian intraglacial substage:		
Sand, yellow, upper 2 feet loess-like	7	
Iowan glacial substage:		
Till, gravelly, oxidized and leached	2	
Sangamon interglacial stage:		
Loess, gray to drab, iron oxide tubules, leached	3	
Kansan glacial stage:		
Gumbotil, very carbonaceous in upper part; exposed	1-3	

The gumbotil is exposed for over 100 yards along the base of the cut. On the south side the material above the till is more distinctly loess-like, although it retains its sandy nature.

The thinness of the Iowan drift in the lobes is shown in a road cut in the SE¼SW¼ sec. 29, Red Oak Township, (T. 81 N., R. 3 W.), Cedar County. This is 100 yards long and shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	1	6
Iowan glacial substage:		
Till, brown, sandy, leached	2	
Kansan glacial stage:		
Gumbotil, gray, typical in every respect, exposed	3	

Another section near here that shows the effect of overriding on older materials is in the SE¼ sec. 36, Cass Township, (T. 81 N., R. 4 W.), Cedar County. Here is an upland cut that showed Kansan gumbotil and old leached Buchanan gravels intermingled and contorted for a depth of 5 feet by the Iowan ice. The oxidized and leached Kansan till is exposed beneath the gumbotil. Above the gumbotil and gravels is 4 feet of sandy Iowan till. Where this is intermingled with the gumbotil, lime concretions and scattered calcium carbonate are still present. The topography also indicates that the surface material is Iowan, as it is constructional rather than erosional. The elevation of the gumbotil is about 790 feet. Figure 29 illustrates Iowan drift overlying distinctive Buchanan gravels near Doris, Buchanan County.

Between secs. 30 and 31, Massillon Township, (T. 82 N., R. 1 W.), Cedar County, 2½ miles east of Clarence, is a shallow cut showing 1 to 3 feet of leached, pebbly Iowan till over Kansan gumbotil and under 2 feet of loess. The interesting point about this section is the fact that the elevation of the gumbotil checked from Clarence proves that the thickness of the Iowan till is at least 45 feet. This is at the south edge of the Clinton lobe of Iowan drift.

A road cut 8 miles north of New Hampton, between the north parts of secs. 31 and 32, Jacksonville Township, (T. 96 N., R. 12 W.), Chickasaw County, shows an interesting section of Iowan that is too thick to be all leached. No loess is evident in the succession, which is as follows:

	Feet	Inches
Iowan glacial substage:		
Till, changed to soil, brown, oxidized, leached	1	
Till, brown, oxidized, leached, few pebbles, compact	3	
Till, brown, sandy, few pebbles, oxidized, unleached		6
Sangamon interglacial stage:		
Loam, dark, sandy, unleached		6

Across the road, on the west side, the unleached till is filled with secondary lime and below it 4 feet of Kansan gumbotil is exposed.

A section in Clayton County shows Iowan that is in part un-

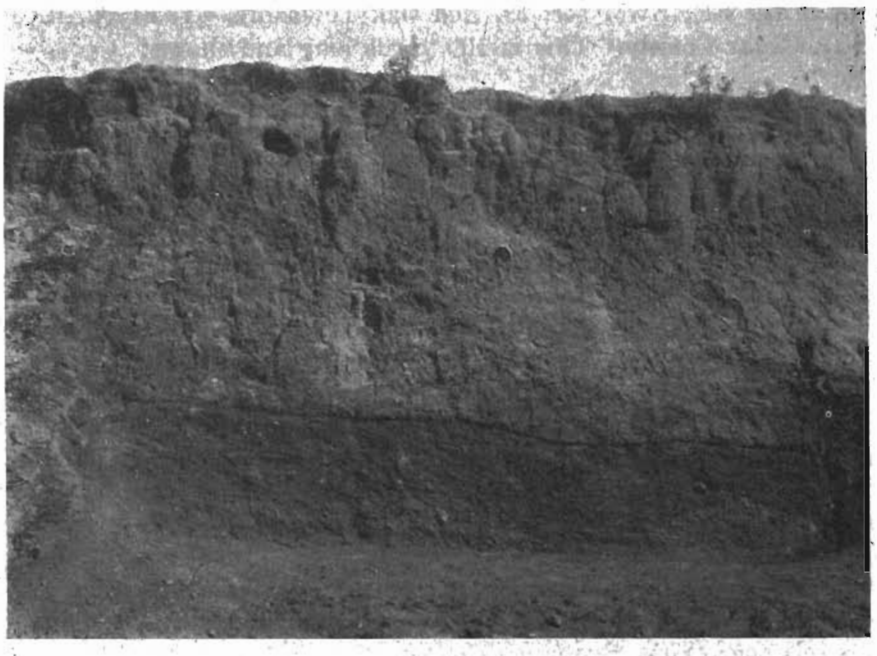

Figure 29. Iowan drift overlying distinctive Buchanan gravels near Doris, Buchanan County.

leached, with no older drift exposed. This outcrop is on the north side of the road along the SE¼ sec. 25, Cass Township, (T. 91 N., R. 6 W.). It showed:

	Feet	Inches
Peorian intraglacial substage:		
Loam and loess-like loam, leached, sandy, dark to brown	1	6
Iowan glacial substage:		
Till, leached, dark yellow to brown, some small boulders	4	6
Till, unleached, oxidized, yellow; exposed	4	

A slight pebble band separates the loam and till.

Sections that show Iowan till thick enough to be unoxidized in its lower part are comparatively rare. One such cut was found along the east side of the road, in the SW¼ sec. 28, Taylor Township, (T. 85 N., R. 10 W.), Benton County. It showed in its deepest part:

	Feet	Inches
Iowan glacial substage:		
Till, brown, sandy to the surface; in places gravelly, yellowish brown to dark brown in color, leached; where till is sandy and gravelly, leaching has progressed about 5 feet, but where till has more clay, it is leached only 3 feet	3-5	

	Feet	Inches
Till, oxidized and unleached, highly calcareous, open textured, cuts readily, sandy, no joints	6	6
Till, unoxidized and unleached, light gray on fresh surface; exposed	1	

Oxidation has advanced along the joints in the unoxidized part and here the color is chocolate brown. The cut lies on level land and hence there probably has been no erosion. It is about 100 yards long and has a greater depth than is usually found in the Iowan.

Another section that shows unoxidized Iowan as well as an unusual thickness of this drift sheet was found in a gravel pit about 2 miles southwest of the Iowa State Teachers College at Cedar Falls, in the NE¼ sec. 27, Cedar Falls Township, (T. 89 N., R. 14 W.), Black Hawk County. The section is:

	Feet	Inches
Iowan glacial substage:		
Loam, leached; above the surface of the Iowan till		6
Till, oxidized, leached, dark yellow	5	
Till, oxidized, yellow. In this zone are chocolate colored unleached gravels	11	
Till, gray on a dry surface, dark gray to black on a fresh surface, highly calcareous. Where the gravels extend down into the till, they are oxidized; exposed	7	

On the surface are some large boulders, one of granite, 6 by 8 by 10 feet. Just where the section was taken a boulder more than 3 feet in diameter lay on the surface of the Iowan with less than 6 inches of loam above. Also several large boulders were lying on the floor of the pit. The maximum thickness of loess-like clay at this pit is 3 feet. In places a faint pebble band may be seen at the top of the Iowan. The gravels show how much oxidized such materials can be while they are still calcareous, and the lower part illustrates very well the blackness of unaltered Iowan. Where the till is gravelly the depth of leaching is greater than where gravel is absent. Leaching must be about at a maximum here as erosion has been very slight.

Sections near the Mankato margin of this eastern area of the Iowan are interesting as showing the uniformity of conditions under which weathering of the glacial and interglacial materials took place. The following road cut is typical. It was made through a low knoll in gently undulating Iowan topography that is mantled with thin loess, and it is located between secs. 35 and 36, Etna Township, (T. 89 N., R. 19 W.), Hardin County. It showed:

	Feet	Inches
Peorian intraglacial substage:		
Loam, dark-brown to chocolate color	1	

Loess, oxidized, yellowish brown, leached	2	
Iowan glacial substage:		
Till, oxidized, brown to brownish yellow, similar in color to the loess; pebbly, fairly compact, leached	2	3
Till, oxidized, yellow, lighter colored than the leached loess; unleached, concretions; exposed	1	

The formation of a soil zone, the leaching of the loess and the weathering of the till, as revealed in this section, are identical with those processes as shown in the eastern counties of the Iowan plain. Similar features are to be seen in Grundy County, and a road cut east of Manly, in the NW¼NE¼ sec. 30, Union Township, (T. 98 N., R. 19 W.), Worth County, showed 7 feet of leached sandy Iowan till overlying Kansan gumbotil that was exposed for a thickness of 4½ feet.

The general uniformity of leaching of Iowan drift and loess is quite striking. The usual thickness of the leached material is about 5½ feet in depth. A series of sections to show this are given below. Two sections near Cleves in Hardin County are interesting because the thickness of the loess is just about the critical depth of leaching. One section at the center of the north line of sec. 2, Clay Township, (T. 88 N., R. 19 W.), shows the following:

	Feet	Inches
Peorian intraglacial substage:		
Loam, dark	1	
Loess, brown to chocolate colored, mealy, leached	4	3
Loess, oxidized, unleached, concretions		3
Iowan glacial substage:		
Till, yellow, pebbly, unleached; exposed along slope	4	
Kansan glacial stage:		
Gumbotil, plowed by Iowan ice; exposed	1	

The next section, which is a mile south, on the west side of the road just north of the south boundary of sec. 2, shows slightly different conditions:

	Feet	Inches
Peorian intraglacial substage:		
Loam, dark	1	
Loess, brown, leached	4	
Iowan glacial substage:		
Till, pebbly, leached		3
Till, unleached; exposed	1	

A large Iowan boulder lies in the field east of the road.

A section in the tongue of Kansan plain that remains between the Iowan and the Mankato drifts shows the similarity of leaching where the loess overlies old drift. It is located in the SE¼SW¼ sec. 11, Eldora Township, (T. 87 N., R. 19 W.), Hardin County, and showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	5	6
Loess, unleached; exposed	2	

Again, in the northwest corner of sec. 8, Palermo Township, (T. 87 N., R. 17 W.), Grundy County, loess is leached to a depth of 5½ feet, right down to the Iowan till, which is entirely unleached.

A gravel pit in the SW¼ sec. 6, Palermo Township, (T. 87 N., R. 16 W.), Grundy County, just at the northeast edge of Grundy Center, shows leaching as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, sandy	4	6
Iowan glacial substage:		
Gravel, leached, fine	1	6
Gravel, unleached, gray to light yellow; exposed	6	

Another pit, this one in the northwest corner of sec. 29, Union Township, (T. 98 N., R. 19 W.), Worth County, shows 4 to 6 feet of loess over the gravels. The loess is all leached, but the gravels are unleached to the base of the loess and are, therefore, Iowan in age. They contain a very large proportion of limestone pebbles. The deposit seems to be an Iowan kame on the Iowan upland.

A road cut on a hilltop in the NE¼ sec. 12, Polk Township, (T. 86 N., R. 9 W.), Benton County, shows no loess but only Iowan till, and this is leached for 5 feet. The upper 2 feet is black with humus but is pebbly to the top. A few secondary lime concretions are present in the upper part.

A pit in the upland 3½ miles north of Independence, in the NE¼ sec. 15, Washington Township, (T. 89 N., R. 9 W.), Buchanan County, shows 1 foot of loam, black above and brown below, then a definite pebble band, succeeded by brown gravels that are leached to a depth of 5½ feet below the surface. Below this the gravels are oxidized but calcareous.

A fine road cut through a small knoll in the NW¼ sec. 20, Paris Township, (T. 98 N., R. 12 W.), Howard County, gave the following succession:

	Feet	Inches
Iowan glacial substage:		
Loam, sandy, leached	1	
Till, leached, typical in every respect	4	6
Till, oxidized, unleached; exposed	1	

Another part of the cut showed only 4½ feet of leached Iowan till, although there is no evidence of erosion. The unleached till is lighter colored than the leached. No loess is present on this knoll; in fact, loess is very thin or absent over most of Howard County.

A section one-fourth of a mile south of Coggan, in the NE¼ sec. 10, Jackson Township, (T. 86 N., R. 6 W.), Linn County, shows an unusual thickness of Iowan till, together with an unusual thinness of leaching.

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached; on a steep slope, so some material may have been carried away and the thickness be immaterial	2	
Loess, unleached, buff	6	6
Iowan glacial substage:		
Till, oxidized but unleached	8	
Till, unoxidized and unleached, gray; exposed in cut and in gutter	11	

In one place the cut gives evidence of plowing of an old clay soil by Iowan ice.

Another good section of Iowan till and loess in a different part of Linn County is shown in the SW¼ sec. 30, Clinton Township, (T. 83 N., R. 8 W.). This cut is surrounded by gently rolling, typical Iowan topography which seems to show no evidence of erosion since Iowan time. Hence, conditions would be especially favorable for maximum weathering.

	Feet	Inches
Peorian intraglacial substage:		
Loess loam, dark gray, many rootlets, filled with humus		4
Loess, somewhat sandy, leached, no pebbles, dark buff in color, open-textured	1	
Iowan glacial substage:		
Till, dark yellow to brown, pebbly, sandy, cuts readily since it is not compact, no jointing seen, faint pebble band at the surface of till; leached	4	
Till, oxidized, unleached, some secondary lime carbonate; sandy, open-textured, no jointing, cuts readily, lighter brown than leached till. Pebbles on slope, most of them less than 2 inches in diameter. To base of cut	5	

In this case the loess is not sharply differentiated from the till and looks as if it were closely related in age to the till.

Another section, this one entirely in Iowan till with no overlying loess, was found in the NW¼ sec. 5, Douglas Township, (T. 98 N., R. 15 W.), Mitchell County. It also illustrates very well the uniformity of leaching over this area, no matter what the material. It presents:

	Feet	Inches
Iowan glacial substage:		
Loam, black, sandy; exposed	1	
Till, Iowan, yellowish brown, pebbly, oxidized, leached	3	6
Till, Iowan, oxidized, unleached, brown with gray spots, secondary lime to top of zone. Transition zone 'two' abrupt, within an inch or so. Exposed	2	

Iowan Drift in Northwestern Iowa

The Iowan drift region that lies west of the Des Moines valley lobe of the late Wisconsin drift has the form of a long, narrow, irregular band whose eastern margin is defined by the western edge of the late Wisconsin plain and whose western margin was determined by the limits of advance of the Iowan ice itself. In defining its limits Carman[71] stated that it

". . is an elongate area extending from Watertown, South Daktoa, across southwestern Minnesota and northwestern Iowa to the south boundary of Sac county, a distance of more than 200 miles. Through Minnesota its width is 10 to 20 miles. South of the state line the belt widens, because of the eastward swing of the Wisconsin boundary, to 40 miles in O'Brien and Clay counties. It narrows again to 15 miles in northern Cherokee and Buena Vista counties and terminates at the south line of Sac county.

"It includes most of that questionable area of northwestern Iowa which has been variously interpreted as covered with Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan, or Kansan drift."

Carman studied the region during several field seasons and finally correlated it with the Iowan of northeastern Iowa because its topography is less maturely erosional than is that of the Kansan plain to the west of it and at the same time is not so youthfully constructional as the Mankato plain on the east.

Carman[72] states, in describing the Iowan drift of northwestern Iowa that

"It is strongly calcareous, even to the surface, there being no leached zone."

This is true, and it doubtless is due to the fact that over most of its area the Iowan drift has a loess cover thick enough to protect it from leaching, either wholly or in greater part. This condition is much more prevalent in the western area than in the eastern Iowan region, and in turn it is probably due to the fact that while the Iowan loess of eastern Iowa was derived from the Iowan till itself, and therefore was blown off the Iowan drift plain, most of the loess of western Iowa was blown *on to* the Iowan drift, chiefly from the Missouri River flats.

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[71]Carman, J. E., Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, p. 39, 1931.

[72]Carman, J. E., *op. cit.*, p. 48.

However, a few sections have been found in which the upper part of the drift was leached, and in each of these instances the evidence was clear that the leaching of the till was possible because of the thinness of the loess. In other words, the same close relation exists here as in eastern Iowa between the thickness of the loess and the leaching or non-leaching of the materials below a certain fairly uniform depth. The depth of leaching is controlled by the character of materials to only a minor extent.

The glacial drift of western Iowa is much thicker than that of the eastern part of the state. In fact in many of the western counties the bedrock is buried beneath 200 to 400 or more feet of glacial materials, and in several counties rock outcrops are entirely absent. Because of this situation very few exposures in northwestern Iowa show contacts of drift and bedrock, and none are recorded in which Iowan drift lies on the indurated rock. No Iowan till has been recognized as lying on Nebraskan or Aftonian material and in only a few localities was till of Iowan age seen in contact with Kansan drift or any post-Kansan-pre-Iowan deposits.

One of the most inclusive and significant exposures of Pleistocene materials in western Iowa, or indeed anywhere in the state, is found in a series of road cuts along State highway no. 5 where it trenches the eastern valley wall of Little Sioux River east of Cherokee. These road cuts display materials ranging in age from Nebraskan till to Peorian loess. The series includes seven cuts between valley floor and upland, and the last two show Kansan till, yellow, oxidized and unleached, and overlain by 2½ feet of Iowan till, sandy, gravelly, oxidized, highly calcareous and with many limestone pebbles. Along part of the exposure a pebble band marks the top of the Iowan till, while elsewhere a narrow drab silt zone demarks the Iowan from the Kansan. Three feet of concretion-bearing loess overlies the Iowan till at the upland level.

A composite section along this slope is about as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, upper 4 feet leached, maximum of	8	
Iowan glacial substage:		
Till	2½-13	
Gravel, unleached	2	
Loveland interval:		
Silt, yellowish, grayish, bluish, unleached; some shells and pebbles, concretions, carbonaceous streaks. Lies in a depression in Kansan till	17	
Loess, gray, some shells and pebbles, unleached; thickness variable.		

	Feet
Kansan glacial stage:	
Till, oxidized and unleached; masses of Nebraskan till in lower part; maximum of	30
Aftonian interglacial age: Weathering and erosion of underlying deposits.	
Nebraskan glacial stage:	
Gumbotil, or till, leached, oxidized; plowed by Kansan till, zone of concretions at base	8
Till, gray, unleached, oxidized in upper part but unoxidized in lower part	16

Another instructive series of beds is seen near the southeast corner of sec. 13, Liberty Township, (T. 93 N., R. 41 W.), in the same county. Here at the bridge crossing of Mill Creek is exposed oxidized and unleached Kansan till rising above water level. Above the bridge are Loveland silts, which are drab to brownish, fossiliferous and unleached. The thickness of the silts is 25 feet, and here the silts are overlain by 6 feet of fresh light-colored gravel and this in turn by a few feet of loess. The gravel and overlying loess are evidently Iowan and Peorian respectively.

About 100 yards north of the corner, along the road between secs. 13, Liberty Township, (T. 93 N., R. 41 W.), and 18, Cedar Township, (T. 93 N., R. 40 W.), a road cut shows above road level 11 feet of fossiliferous loess, of which the lowest 3 feet is bluish while the upper part is gray. Above this loess, which is Loveland in age, lie 4 to 5 feet of fresh Iowan gravels and above them is Peorian loess, brown in color and leached for 5½ feet below the surface. The lower 2 inches of loess is unleached, and the underlying gravels are also unleached.

A mile south and half a mile east of this corner, where the road through the middle of sec. 19, Cedar Township, (T. 93 N., R. 40 W.), crosses Mill Creek, is another significant section. Piecing together the elements of the different exposures we get the following:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	2	
Iowan glacial substage:		
Till, sandy, oxidized, unleached	3	
Loveland interval:		
Silts, gray to drab where fresh, light gray on dry surface, laminated, fossiliferous, unleached	5	6
Kansan glacial stage:		
Till, oxidized, calcareous.		
Till, unoxidized, unleached, bluish black.		

A somewhat different series of materials is exposed in a group of stream cuts southeast of Cherokee, in Pilot Township, (T. 91 N.,

R. 40 W.). In the southwest corner of sec. 1, the creek has cut into its south bank and exposed:

	Feet	Inches
Peorian intraglacial substage:		
Loess; thickness variable		
Iowan glacial substage:		
Gravel and sand, fresh, in places	5	
Till, fresh; thickness variable.		
Loveland interval:		
Silts, in places forming upper part of outcrop, here passing into soil, leached	3	
Silt, blue gray, with sandy streaks, leached	2	
Silt, blue gray, some sandy streaks, leached	3	
Sand, yellowish, with blue gray bands, leached	2	
Silt, dark gray to drab, leached	2	6
Sand and silty sand, yellow, pebble streaks, calcareous at base	1	6
Gravels, coarse, with cobbles and boulders	5	
Nebraskan glacial stage:		
Till, upper part leached, to base of cut	13	

Within sight of this exposure, about 200 yards down stream, across the highway and the railroad, in the southeast corner of sec. 2, the creek has cut into its west bank and exposed a comparable section.

	Feet	Inches
Iowan glacial substage:		
Till, or clayey gravel, fresh	6	
Loveland interval:		
Loess and sandy loess, buff, leached	4	
Silt, loess-like, dark gray to drab, sandy streaks, probably mainly loess, leached	6	
Silt, dark blue, with brownish sandy layers, leached	4	
Gravel, coarse, unleached to base; exposed	6	

Kansan till may be seen close by at the lower level of this cut.

About one-half mile south of these cuts, in a ravine in the SE¼ NE¼ sec. 11, may be seen a fine section showing Loveland materials lying in a depression in Nebraskan till. It is as follows:

	Feet	Inches
Loveland interval:		
Clay, buff to brownish, loess-like, with a few thin seams of sandy material, leached	6	
Silts, sandy and gravelly, calcareous	3	
Silt, gray, sandy, calcareous, a few fossils	5	
Gravel and sand, mottled dark brown, some MnO_2, calcareous	5	6
Gravel, coarse, rusty, much MnO_2, calcareous. Thickness variable.		
Silt, dark gray, sandy, calcareous, some carbonaceous material	2	

Nebraskan till rises about 8 feet above the base of the exposure on the south side and may be seen also on the opposite side, showing the presence of a depression in the till. In one place a few feet of oxidized Kansan till intervenes between the Nebraskan and the Loveland. Here the silts are leached for 7 feet. On the surface an Iowan boulder was observed. Horizontal laminae are plainly to be seen in the silts.

Leaching of the Iowan materials seems to have differed considerably in depth, although most probably these differences are not greatly significant, showing chiefly effects of location, erosion or other local factors. Two road cuts near to each other in Pitcher Township, (T. 91 N., R. 39 W.), Cherokee County show rather marked variaton in this regard. One of these is in the NW¼ sec. 24 and shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	2	9
Iowan glacial substage:		
Till, oxidized, leached		9
Till, unleached; exposed	3	

The other is a mile south, in a gently rolling region in the NW¼ sec. 25. It revealed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, upper 6 inches loamy and filled with humus, brown, leached	4	9
Loess, oxidized yellow to buff, unleached		3
Iowan glacial substage:		
Till, oxidized, unleached	1	

Another road cut, this one in the SE¼ sec. 28, Afton Township, (T. 92 N., R. 39 W.), not far from a tributary of Little Sioux River, showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, oxidized	5	4
Loess, oxidized, unleached; exposed		6

A similar depth of leaching in loess was observed on the east line of the SE¼ sec. 26, Pilot Township, (T. 91 N., R. 40 W.), on fairly level upland.

Exposures in other counties of the Iowan area show a similar range in depth of leaching. For instance, near Early, in Sac County, the following sections are illustrative. A gravel pit near the southwest corner of sec. 10, Boyer Valley Township, (T. 88 N., R. 36 W.), shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, brown, oxidized, leached	3	
Gravel, oxidized, leached		6
Gravel, unleached; exposed	8	

These are Iowan upland gravels. Some large boulders are present.

On the south side of the SE¼ sec. 3 of this township a road cut showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, brown, leached	5	
Iowan glacial substage:		
Till, brown, sandy, pebbles, some of limestone, leached; exposed		9

This cut is on the flat Iowan upland, about a mile west of the Mankato drift boundary.

Nearly 4 miles west, on the south side of the SW¼ sec. 6, Boyer Valley Township, (T. 88 N., R 37 W.), another road cut on the level upland showed:

	Feet	Inches
Peorian intraglacial substage:		
Loam	1	
Loess, leached	4	
Iowan glacial substage:		
Till, pebble band at top, clay among pebbles is calcareous, as is till below; exposed	1	

Just southeast of Dickens in the NW¼ sec. 20, Freeman Township, (T. 96 N., R. 35 W.), in Clay County, and still in the Iowan area, is a section that showed:

	Feet	Inches
Peorian intraglacial substage:		
Soil, dark, humus filled		6
Loess, brown, leached	3	
Iowan glacial substage:		
Till, oxidized, leached		6
Till, unleached, exposed	2	

This section shows an intermediate depth of leaching. The minimum amount is found in a road cut between secs. 4 and 9, Carroll Township, (T. 96 N., R. 42 W.), O'Brien County. It showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess	1-3	
Iowan glacial substage:		
Till, highly calcareous	2-3	
Loveland interval:		
Loess or silt, gray, plowed, highly calcareous	½-2	
Loess, dark gray or buff, calcareous, then 1½ feet of light buff, leached, then 1½ feet, light buff, slightly calcareous. No till exposed below.		

An excellent section at the railroad crossing on the east line of sec. 12, Union Township, (T. 94 N., R. 41 W.), O'Brien County, showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	5	
Iowan glacial substage:		
Till, light yellow on surface, brownish when fresh, mealy, oxidized, unleached. A pebble band which includes limestones. Exposed	12	

Another interesting exposure illustrating leaching is in a gravel pit in the southwest corner of sec. 8, Liberty Township, (T. 94 N., R. 40 W.), of this same county. It showed:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached	3-4	
Iowan glacial substage:		
Gravel, valley type, fresh to contact with loess	8	
Till, oxidized, calcareous. Base not seen		

Several other sections in loess near Paullina in O'Brien County show about 4 feet of leaching, as on the west line of the NW¼ sec. 15, Union Township, (T. 94 N., R. 41 W.), where 4 feet of leached loess overlies a pebble band on fresh Iowan; in the SW¼ sec. 10, Union Township, (T. 94 N., R. 41 W.), and in the NE¼ sec. 9, Liberty Township, (T. 94 N., R. 40 W.), where on level land, 3 feet 10 inches of loess was exposed over unleached loess; also in the Kansan area, on the south line of the SE¼ sec. 1, Caledonia Township, (T. 94 N., R. 42 W.), which showed 4 feet 4 inches of leached loess, below which was exposed a foot of unleached loess. On the opposite side of the road, however, loess and till together were leached only 2 feet 7 inches, 1 foot of this being till.

Two sections in East Holman Township, (T. 99 N., R. 41 W.), Osceola County, are interesting as giving a contrast in the amount of leaching in the Iowan and Mankato areas. One of these road cuts, on the south line of the SE¼ sec. 11, about a mile within the margin of the Mankato drift plain, showed:

	Feet	Inches
Mankato glacial substage:		
Loam, black, leached	1	
Till, brown, pebbly, oxidized, leached	1	6
Till, yellow, oxidized, unleached; exposed	1	

In contrast, another cut 4 miles to the west, on the south line of the SE¼ sec. 7, (T. 99 N., R. 41 W.), and on the Iowan plain, presented:

	Feet	Inches
Peorian intraglacial substage:		
Loam, black to brown	1	
Loess, lighter brown to yellow, leached	3	
Iowan glacial substage:		
Till, yellow, oxidized, many limestone pebbles. Clay leached for a few inches, but limestones fresh; exposed	1	

No loess is present in the first cut, and leaching has progressed only 2½ feet. In the Iowan area, several feet of loess overlies the till, and leaching has advanced 4 feet, which is also about the depth of leaching in loess over the Kansan drift.

Gravel pits have been operated at Sibley for many years, and thorough studies have been made of the deposits, especially by Carman.[73] In general these pits show 3 to 4 feet of loess, all leached down to the gravels, which, however, are fresh to their contact with the loess. Inclosed within these gravels are masses of yellow unleached Iowan till.

Similar conditions as to thickness and leaching of loess and underlying materials prevail to the western margin of the Iowan area. Road cuts and other exposures within the Iowan region are in general so shallow that little or no idea of the thickness of the Iowan drift can be obtained. One or two sections will explain conditions on both sides of the margin. In the southwest corner of sec. 12, Grant Township, (T. 99 N., R. 43 W.), Lyon County, a road section in the upland Iowan plain revealed:

	Feet	Inches
Peorian intraglacial substage:		
Loam, black	1	
Loess, brownish, leached	3	
Iowan glacial substage:		
Till, yellow, limestone pebbles abundant, clay leached a few inches, below that unleached; exposed	2	

This exhibits about the average amount of leaching for this region. Farther west, in the Kansan region, a road cut in the middle of the south line of sec. 32, Midland Township, (T. 100 N., R. 44 W.), Lyon County, showed about the minimum leaching found outside the Mankato plain, namely 3½ feet, while another section just south of Rock Rapids, on the east line of the SE¼ sec. 8, Rock Township, (T. 99 N., R. 45 W.), revealed a depth of leaching, 4½ feet; that seems to be about normal. The unleached yellow loess is here about a foot thick over the till.

As one travels westward from the Mankato margin over the

[73]Carman, J. E.. The Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 26, pp. 386-391, 1917.

Iowan plain and then over the Kansan region, a noteworthy thickening of the loess is observable, but the amount of leaching in this loess—or where it is thin enough to be leached to its base, in the underlying till or gravel—is fairly uniform within a certain range of variation. One gets the impression that the average of leaching in this northwestern region of Iowa is nearer 4 or 4½ feet than the 5½ feet that is so common in eastern Iowa.

Descriptions of the Drift Phases

Iowan Boulders

One of the most striking characteristics of the Iowan drift and its topography is the great number of boulders that are displayed. All of the drifts are boulder-bearing, but the Iowan ice, for some reason, seems to have brought down more large boulders than any of the other ice sheets.

A noteworthy feature of these boulders is the fact that most of them are of the lighter colored granitic types rather than the darker ferro-magnesian kinds which form so large a percentage of the boulders of the Kansan and Nebraskan till sheets. Alden and Leighton[74] mapped the locations of large granitic boulders in Iowa and the relationships of these boulders to the northeastern area of Iowan drift are shown in figure 30.

Another factor that aids in making the Iowan boulders conspicuous is the thinness or absence of the loess over the Iowan plain. Doubtless, many boulders are buried in the loess of southern Iowa, but this is not possible, at least not to the same extent, in the Iowan area, for both the loess and the drift are thinner here.

Boulders are common sights in the landscape of nearly all parts of the Iowan, but they are noted especially in the eastern counties, where some of great size were present in earlier days. Many of these have been broken up and removed but a goodly number of large ones still form notable landmarks.

Calvin,[75] in describing the Iowan drift of Howard County, used these words, that are very inclusive, in describing these rocks:

"The bowlders are coarse-grained and light colored, and it is a surprising fact that in all northeastern Iowa approximately three-fourths of the entire bulk of the Iowan erratics represent but one type of granite which might all have come from a single locality. Iowan boulders are large and numerous as compared with bowlders in the Kansan drift, but the variety and number of rock species are far greater in the Kansan than in the Iowan."

[74]Alden, W. C., and Leighton, M. M., The Iowan drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, vol. 26, p. 122, 1917.
[75]Calvin, Samuel, Geology of Howard County: Iowa Geol. Survey, vol. 13, p. 68, 1903.

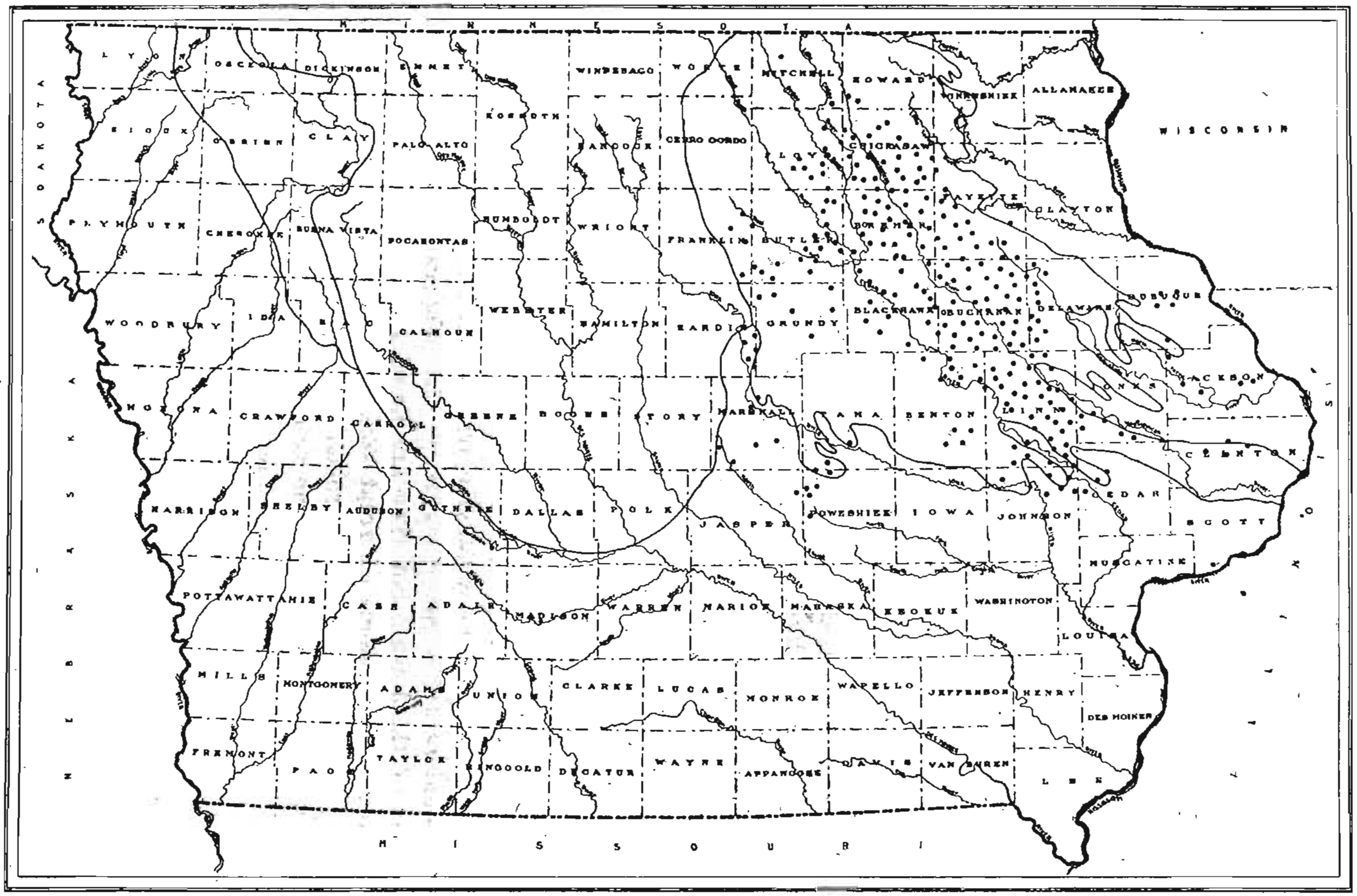

Figure 30. Map of Iowa showing the locations of large granitic boulders in and adjacent to the Iowan drift area. (Modified from Alden and Leighton, 1917.)

Calvin pictures a boulder of this type in sec. 22, Jamestown Township, (T. 99 N., R. 14 W.), Howard County, that is 20 by 12 by 9 feet in dimensions, and Williams[76] describes one in Worth County, north part of sec. 14, Kensett Township, (T. 99 N., R 20 W.), that is 20 by 12 feet in horizontal dimensions and rises 12 feet above the ground.

In the SW¼ sec. 18, Dresden Township, (T. 94 N., R. 12 W.), Chickasaw County, many and large boulders were noted, also for several miles south, somewhat as if they might have been left in a boulder train by the ice, (fig. 31). They are especially numerous and large in the swales, although they also lie well up on the slopes.

Figure 31. Field of Iowan boulders south of Bassett, Chickasaw County.

In one field of a few acres extent 21 large ones were counted, many of them more than 10 feet in smaller diameters. The largest boulder in this county, and perhaps the largest in the state, is known as St. Peter. It lies in the SW¼ sec. 3, Washington Township. (T. 97 N., R. 13 W.), and is fully 20 feet high and over 80 feet in circumference (fig. 33).

[76]Williams, I. A., Geology of Worth County: Iowa Geol. Survey, vol. 10, p. 362, 1900.

Savage,[77] in his description of the geology of Fayette County, states that these

"large granite masses are conspicuous in the townships of Jefferson, Oran, Freemont, Banks and Bethel. Near the eastern border of the Iowan drift plain the boulders are even more abundant, but they are usually much smaller in size."

They have also been noted between Fayette and Maynard and from West Union to New Hampton.

Norton,[78] in the course of a thorough discussion of the Iowan boulders of Bremer County, mentions the excess of granites over darker types; the freshness of most of the boulders, also their faceted and scored surfaces, showing that they were carried at the base of the ice and of the drift; the fact they

"affect the lower ground, the swales and draws, and are less often seen upon the low crests of the gently undulating plain."

He also states that

"The boulders of Bremer county, while by no means rare, do not seem by any means as plentiful as those of the areas nearer the eastern margin of the Iowan drift."

He shows views of several boulder groups, but states that they are exceptional. Some boulders mentioned are: one in sec. 1, Douglas Township, (T. 93 N., R. 13 W.), that is 20 by 12 by 8 feet, while another 1½ miles southeast of Frederika, is 22 by 15 by 4 feet above ground. He speaks of one 2½ miles north of Sumner that was described by McGee as being 25 by 40 feet in diameter and rising 11 feet above ground. Much had been quarried away and most of the rock appeared to be buried in the ground.

Butler County is another of those in which boulders are abundant, some large and relatively solitary, others small and thickly sprinkled on the fields. Arey[79] says that

"In places boulders are surprisingly abundant while elsewhere they are wholly wanting or found only in the sags. Pilot Rock, in the west half of section 23, West Point township, has a girth of 99 feet and maximum height of 12½ feet."

Buchanan County is one of those most noted for the size and number of its erratics, (fig. 32). In early days these were abundant on every hand. Calvin[80] stated that

"Boulders ten, fifteen or twenty feet in diameter, and standing conspicuously above the general surface, are common features of the prairie landscapes, and great granite masses, thirty feet in diameter, are known at several points. Multitudes of smaller boulders, ranging from three feet in diameter, are a serious encumbrance in many fields and pastures."

[77]Savage, T. E., Geology of Fayette County: Iowa Geol. Survey, vol. 15, p. 528, 1905.
[78]Norton, W. H., Geology of Bremer County: Iowa Geol. Survey, vol. 16, pp. 372-375, 1906.
[79]Arey, M. F., Geology of Butler County: Iowa Geol. Survey, vol. 20, p. 19, 1910.
[80]Calvin, Samuel, Geology of Buchanan County: Iowa Geol. Survey, vol. 8, p. 245, 1898.

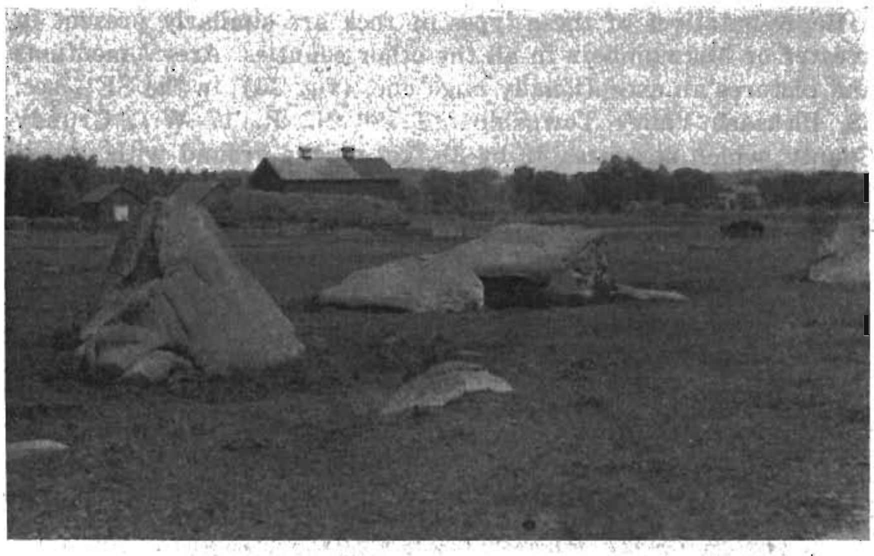

Figure 82. Large Iowan boulders in Buchanan County.

Figure 83. Large Iowan boulder in Chickasaw County.

Representatives of these types of rock are similarly present in greater or less numbers in all the other counties. Arey[81] mentions and pictures an exceptionally huge one, (fig. 34), in the SE¼ sec. 38, Pleasant Valley Township, (T. 89 N., R. 17 W.), Grundy County, which measures 32 by 28 feet on the ground with an exposed height of 10 feet. He also mentions another nearly as large and further states that

"The western part of Pleasant Valley township has an unusual number of large boulders, as do portions of Beaver and Fairfield townships."

Figure 34. Iowan boulder in Grundy County measuring 32 by 28 feet with an exposed height of 10 feet.

The Iowan Pebble Band

The senior author, in 1931, published a paper[82] on the pebble band on Iowan till. In this paper it is stated that within the area of Iowan drift in northeastern Iowa, thin Peorian loess overlies in many places a distinct pebble band at the surface of the Iowan till. Where the pebble band is absent, the loess lies directly on the till. Where no loess is present on the till, the till in upland sections is leached to a depth of approximately 5 feet. Where loess

[81]Arey, M. F., Geology of Grundy County: Iowa Geol. Survey, vol. 20, p. 86, 1910.
[82]Kay, G. F., Origin of the pebble band on Iowan till: Jour. Geology, vol. 39, pp. 377-380, 1931.

is on the pebble band or on till and is of sufficient thickness to be unleached in its lower part, the underlying Iowan till is unleached to its surface. Where the loess is thin and leached, the upper part of the till is leached also, whether the pebble band is or is not present, the combined leaching of the loess and till being about the same in depth as where no loess overlies the till.

Thick Peorian loess which is apparently genetically related to the Iowan till is uniformly present beyond the borders of the Iowan drift where presumably good anchorage was afforded by the vegetation of the extra-marginal Kansan drift areas. This loess thins with distance from the Iowan; and, furthermore, the constituent parts of the loess are largest at the border of the Iowan and become smaller and smaller as distance increases from the border.

Figure 35. Pebble band with Iowan till below and Peorian loess above, Fremont Township, Cedar County

One of the best exposures within the whole Iowan area showing the line of pebbles with Iowan till below and loess above was observed in a road cut in the middle of the line between secs. 1 and 2, Fremont Township, (T. 82 N., R. 3 W.), Cedar County (fig. 35). This cut is in an area of gentle topography. The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, oxidized to brownish color, leached	4	
Iowan glacial substage:		
Pebble band, a thin row of pebbles.		
Till, oxidized, grayish yellow to yellow color, no ferretto, sandy, contains sand pockets, jointed, upper 1 foot 3 inches leached, lower part unleached	5	

Here some of the fragments of rock in the pebble band show wind polish (fig. 36). But in many places the pebbles of the pebble bands lack evidence of wind action. Nor do the pebbles show surface effects due to water action; they are similar to the pebbles which are common in glacial till.

Another good section showing a pebble band is at Denver Junction, Jefferson Township, (T. 91 N., R. 13 W.), Bremer County, (fig. 37).

Figure 36. Wind polish on boulder from pebble band, Fremont Township, Cedar County.

A road cut near the center of sec. 32, Deer Creek Township, (T. 100 N., R. 19 W.), Worth County, shows the following section:

	Feet	Inches
Peorian intraglacial substage:		
Loam or clay, loess-like	1	6
Iowan glacial substage:		
Till, with striated cobblestones, a distinct pebble band on top	1	
Kansan glacial stage:		
Gumbotil, typical; exposed	2	6

This cut was made through a swell on the drift plain; the Iowan till is very thin. The swell is a feature of a level stretch of country south of Northwood.

At the crossroads just east of Oelwein, (T. 91 N., R. 9 W.), Fayette County, is a good section showing:

	Feet	Inches
Peorian intraglacial substage:		
Loess-like clay	2	
Iowan glacial substage:		
Pebble band		
Till, yellow, leached	3	

Another cut in the middle of sec. 22, Jefferson Township, (T. 91 N., R. 9 W.), of the same county shows a fine distinct pebble band that conforms to the slope of the land surface. It lies on the top of Iowan till and is overlain by loess-like clay. Some of the cobbles in the pebble band extend up into the clay.

A well developed pebble band is at the middle of the south half of the line between secs. 34 and 35 of Lincoln Township, (T. 87 N., R. 14 W.), in Black Hawk County. This section shows under 3

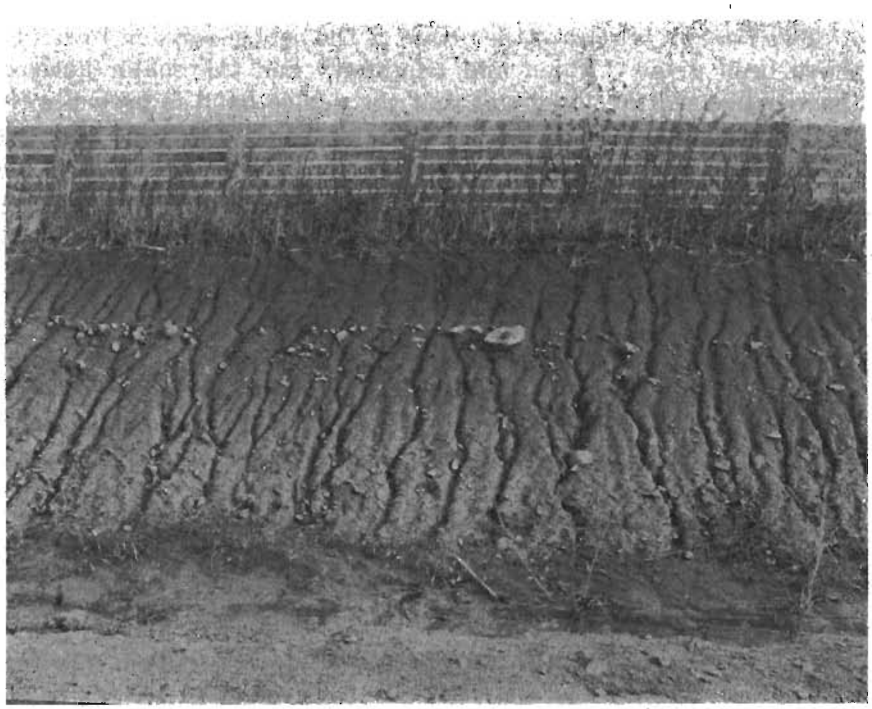

Figure 37. Pebble band on Iowan till just west of Denver Junction, Bremer County.

feet of a loamy clay, a well developed pebble band. Beneath this is Iowan till with a maximum thickness of 3 feet, and below this is Kansan gumbotil.

Near the middle of sec. 25, Clinton Township, (T. 83 N., R. 8 W.), Linn County, a cut shows Iowan till forming a mound and having a pebble band at the top. The whole is covered by thin loess.

A pebble band occurs in a cut at the corners of secs. 28, 29, 32, 33, Massilon Township, (T. 82 N. R. 1 W.), Cedar County. This exposure shows 3 feet of leached loess lying on a distinct pebble band, on Iowan till. Some of the pebbles show evidence of wind polishing.

Pebble bands were observed also at the middle of the line between secs. 27 and 28, Cedar Township, (T. 97 N., R. 16 W.), Floyd County, at the top of gravelly Iowan till, with a little loam above; between Frederika and Waverly in Bremer County, where they were seen with striking frequency in the shallow roadside cuts; in several cuts between Fayette and Maynard, in Fayette County; and in many other cuttings into the Iowan plain.

Pebble bands are also found in places on the Iowan till in northwestern Iowa.

Two interpretations of the origin of the pebble band on Iowan till have been given. Alden and Leighton[83] and the senior author[84] have expressed the judgment that the pebble band is probably the residual coarse material left from the slight wind erosion and rain wash which occurred in places before the till was protected by the loess. The evidence suggests strongly that the pebble band was formed and the overlying loess was deposited in a comparatively short time after the deposition of the Iowan till. In fact, the area within which the pebble band was developed was probably a marginal area free from vegetation in front of the retreating Iowan ice sheet. Winds blowing outward from the diminishing glacier picked up the fine material from the ground moraine and outwash areas from which the ice sheet had withdrawn, leaving a pebble band, which soon afterward was covered by loess which was being deposited and redeposited within the area of wind action.

The second interpretation of the origin of the pebble band has been advanced by Leverett.[85] He considers the pebble band to have been the result chiefly of the erosion of several feet of the Iowan till by running water, and that considerable time was involved in its

[83]Alden, W. C., and Leighton, M. M., The Iowan drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, vol. 26, pp. 83-156, 1917.

[84]Kay, G. F., The relative ages of the Iowan and Illinoian drift sheets: Am. Jour. Sci., vol. 16, pp. 506-508, 1928.

[85]Leverett, Frank, The Pleistocene glacial stages: were there more than four? Am. Phil. Soc. Proc. vol. 65, p. 111, 1926.

formation. He favors the view that the till on which the pebble band was formed was the result of an ice sheet from the Keewatin field and equivalent in age to a late phase of the Illinoian drift. He is of the opinion that the time between the deposition of the till within the Iowan area and the deposition of the overlying Peorian loess was comparable to the time between the deposition of the Illinoian drift and the deposition of the Peorian loess overlying the Illinoian drift. He would make the Iowan drift the product of a late phase of the Illinoian age of glaciation and would apply the name Sangamon to the interval between the time of deposition of the Iowan and that of the overlying Peorian loess as well as to the time of deposition of the Illinoian drift and that of the Peorian loess which overlies it. On this interpretation the pebble band was formed not by wind action but chiefly by slope wash during the long Sangamon interval.

An aid to the solution of the problem of the origin of the pebble band has been presented by Hobbs[86] who has found similar phenomena in Greenland. He states:

"All the characteristic effects of the wind within the better-known desert areas of lower latitudes are here found reproduced on or about the outwash plains of the continental glacier of Greenland--there are the Armored floor (pebble bed), the loess deposits within a zone marginal to the glacier, scattered boulders profoundly etched by sand-blast erosion--and all explained by the wind of the glacial anticyclone generated by the glacier itself and operating upon its own outwash deposit."

Later in his paper he states:

"The Greenland ice sheet is surrounded by a rugged plateau deeply dissected and representing differences of level of several thousand feet; whereas the continental glaciers of North America lay over much flatter country. Within the middle Mississippi Valley the zone of outwash, instead of being restricted to the heads of fjord valleys, as it now is in Greenland, must have formed an almost continuous zone marginal to the ice sheet. Under such conditions one may picture a zone of loess marginal to the ice, deposited in places upon till, and exhibiting thin pebble beds and scattered boulders which are etched by the sand blast as these have been found in Iowa particularly. Deposits of till would also to some extent supply materials for wind transport. In Southeast Greenland, however, there is found but little till to be affected."

Oxidized and Leached Iowan Till

The uppermost phase of the Iowan till proper is oxidized and leached till, as no gumbotil has been formed on the till. The normal sequence of drift phases of the three older tills includes gumbotil, oxidized and leached till, oxidized and unleached till, and unoxidized and unleached till, in downward succession, the

[86]Hobbs, W. H., Loess pebble bands, and boulders from glacial outwash of the Greenland Continental glaciers: Jour. Geology, vol. 39, pp. 381-385, 1931.

gumbotil phase representing the product of greatest weathering and alteration occurring on the uneroded uplands during the long interglacial ages.

The lack of a gumbotil on the Iowan drift is due to incomplete weathering and chemical alteration, which in time, would change the oxidized and leached surface drift materials into the dense, tenacious, drab, deoxidized till residuum of typical gumbotil such as is found on earlier drift sheets. This incompleteness of the weathering processes is believed due solely to the shortness of time which has elapsed since the deposition of the Iowan till.

The evolution of the various phases of a drift undergoing the changes brought about by surface weathering agencies indicates that the first phase formed on a freshly deposited till is oxidized and unleached till. Oxidation of the drab or dark-gray fresh till begins immediately upon exposure of the drift materials to the atmosphere. Beginning as quickly but progressing downward with extreme slowness, the process of leaching follows oxidation behind a widening interval of the oxidized but unleached till. Upon the leached and oxidized surface of this second phase of change, the gumbotil develops only when a great length of time permits the chemical modifications necessary to remove the remaining soluble content, as well as colloidal clays and silicates from the already weathered drift. Time is the prime factor, with variations in the original till lithology seeming to play but a minor part in the final residual product.

Insufficient time has elapsed since Iowan till deposition for the formation of an Iowan gumbotil horizon.

The color of the oxidized and leached phase is predominently brown to dark brown. In mass texture this phase is sandy and pebbly and cuts readily. It is open-textured. In many places a concentrate of pebbles, the pebble band, is found at the top of this phase, formed as a residue of the surface material after the finer parts had been blown away as sand, silt, and dust. No distinct concentration of iron oxide, the ferretto zone, is found capping this upper phase of the Iowan till.

The clastic texture of the oxidized and leached Iowan till is slightly coarser than that of the same zones of the three older tills, the Nebraskan, Kansan, and Illinoian, a fact which can be represented best by a comparison of the average analyses shown in figure 6, page 34. In the Iowan till the average percentage of material below 1/64 millimeter in diameter is about 32 in comparison to 48 in the Illinoian, 39 in the Kansan, and 33 in the Nebraskan. The size grade between 1/32 and 1/64 millimeter in diameter in the Iowan till is a minimum percentage of about 8 percent, while in the older tills this size grade is between 11 and 17 percent, one of the three largest percentages of the analysis. About 50 percent of the material of the Iowan till is grouped into the size grades between 1/32 and 1/2 millimeter in diameter in comparison to about 49, 43 and 32 percent in the Nebraskan, Kansan, and Illinoian respectively.

An average of the analyses of pebbles from oxidized and leached till from eight locations distributed throughout the Iowan drift area of this state is given in the accompanying table.

	Kansan Till, Oxidized and Leached	Iowan Till, Oxidized and Leached	Kansan Till, Oxidized and Unleached	Iowan Till, Oxidized and Unleached	Kansan Till, Oxidized and Unleached (Limestone excluded)	Iowan Till, Oxidized and Unleached (Limestone excluded)
Greenstone	25.00	40.50	27.00	28.00	40.30	52.80
Greenstone schist	1.30	1.00	1.00		1.50	
Granite	22.30	18.70	14.00	16.00	20.90	30.20
Diorite	5.15	2.10	2.00	2.00	3.00	3.80
Syenite	2.60					
Porphyry	1.30	1.00	1.00	1.00	1.50	1.90
Other crystallines	4.72	2.10	2.00	1.00	3.00	1.90
Quartzite	19.70	4.16	5.00	1.00	7.50	1.90
Quartz	9.27	8.28	3.00	1.00	4.50	1.90
Sandstone	3.90	4.16	2.00	1.00	3.00	1.90
Limestone			34.00	45.00		
Chert	21.00	16.70	9.00	2.00	13.40	3.80
Shale	2.60					
Clay ironstone		1.00	2.00	1.00	3.00	1.90
Hematite—jasper	1.30					

This analysis is very similar to an average of several analyses of the pebbles from the oxidized and leached zone of the Kansan till which lies directly below the Iowan till. The lack of limestone and other easily weathered rock common in fresh till is evidence that there has been alteration of the lithology and at the same time texture by chemical weathering. However, if one excludes the limestone and dolomite from an analysis of unleached and oxidized Iowan till, there is a difference in the percentages of the remaining types of rocks, as compared with the leached and oxidized, shown chiefly in a smaller percentage of such rocks as greenstones and granites and an increase in the percentages of quartzite and chert. To determine whether this was an accidental variable within the Iowan till, similar analyses were made using comparable analyses from the oxidized and leached and the oxidized and unleached Kansan till. The results of this study correlated very closely as shown in the preceding table.

From the study of the lithology and shapes of the leached and unleached Kansan till in comparison to the Iowan till, it may be concluded that the differences in size grades, determined by the mechanical analyses, are due to the differences in the clastic texture of the original material and are not the result of a greater amount of weathering and disintegration in the older tills.

Oxidized and Unleached Iowan Till

The oxidized and unleached phase of the Iowan till is found below the oxidized and leached phase, set off by a narrow transitional zone in which the line of effervescence to acid traces the interfingering contact between the two phases. The two phases are not easily differentiated except with the aid of acid. The color of the oxidized and unleached till is yellow, being lighter colored as a whole than the yellow-brown till of the overlying oxidized and leached phase.

Concretions are frequent in this phase, and occur noticeably in the upper part, where lime-bearing waters active in the process of leaching in the till phase above, have penetrated the lime-filled unleached till, resulting in the precipitation of secondary calcium carbonate.

The till is open-textured, with no prominent system of joints, and in mass texture closely resembles the phase above.

There is a general similarity among the clastic textures of the oxidized and unleached Iowan till and the oxidized and unleached Nebraskan, Kansan, and Illinoian tills as shown in the average analyses in figure 6, page 34. In the Iowan till, about 30 percent of the material is included in the maximum size grade which is that finer than 1/64 millimeter in diameter. The next coarser size grade, 1/32 to 1/64 millimeter in diameter, contains only 8 percent. This is followed by a secondary maximum of 18 percent. The coarser size grades have a general decrease in percentage with increasing size grades.

There is a marked difference between the lithology of the oxidized and unleached and the oxidized and leached Iowan till. This difference is illustrated by a comparison of the pebble analyses of the two types in the table, page 137. The most pronounced differences revealed by the comparison are in the presence of a very high percentage of limestone, a higher percentage of granites and greenstones, and a lower percentage of chert, quartzite, and other siliceous rocks in the oxidized and unleached till. These differences are all explained by the chemical weathering which will disrupt the more soluble constituents first, such as limestones, greenstones and granites, increasing the percentages of the less soluble siliceous rocks such as quartzites and chert. Further evidence that chemical weathering has not been active in the oxidized and unleached till is shown by the original shapes of even the most soluble fragments such as limestone. This is shown by striations, scratches, and bruises received during transportation, which are still on the surfaces of all types of material. Analyses of the shapes of the grains show practically no rounding by solution.

Unoxidized and Unleached Iowan Till

The basal phase of the Iowan till, the unoxidized and unleached phase, is frequently missing in sections of Iowan till due to the extreme thinness of the till sheet, allowing for oxidation to the base. However, several excellent sections show the unoxidized and unleached phase and a few of these have been previously described.

The unoxidized and unleached phase differs distinctly from the overlying phase in the color of the till, but in other respects is identical. The unoxidized till is gray on a dry surface, becoming dark gray to black when wet. Along the surfaces of the occasional joints extending down into this phase, oxidation has occurred which has outlined the joint system with the chocolate-colored veneer of incipient oxidation. As in the older tills the color line that is the oxidation line between the oxidized and unoxidized phases of the unleached till, is irregular, resulting in a zone of transition which may be several feet thick.

In mass texture, the unoxidized and unleached phase is more compact, less easily cut, more visibly jointed, than the overlying phases.

The clastic texture of the unoxidized and unleached Iowan till is not distinctly different from the clastic texture of the oxidized and unleached Iowan till. The graphic representation of the mechanical analyses in figure 6, page 34, shows minor variations and

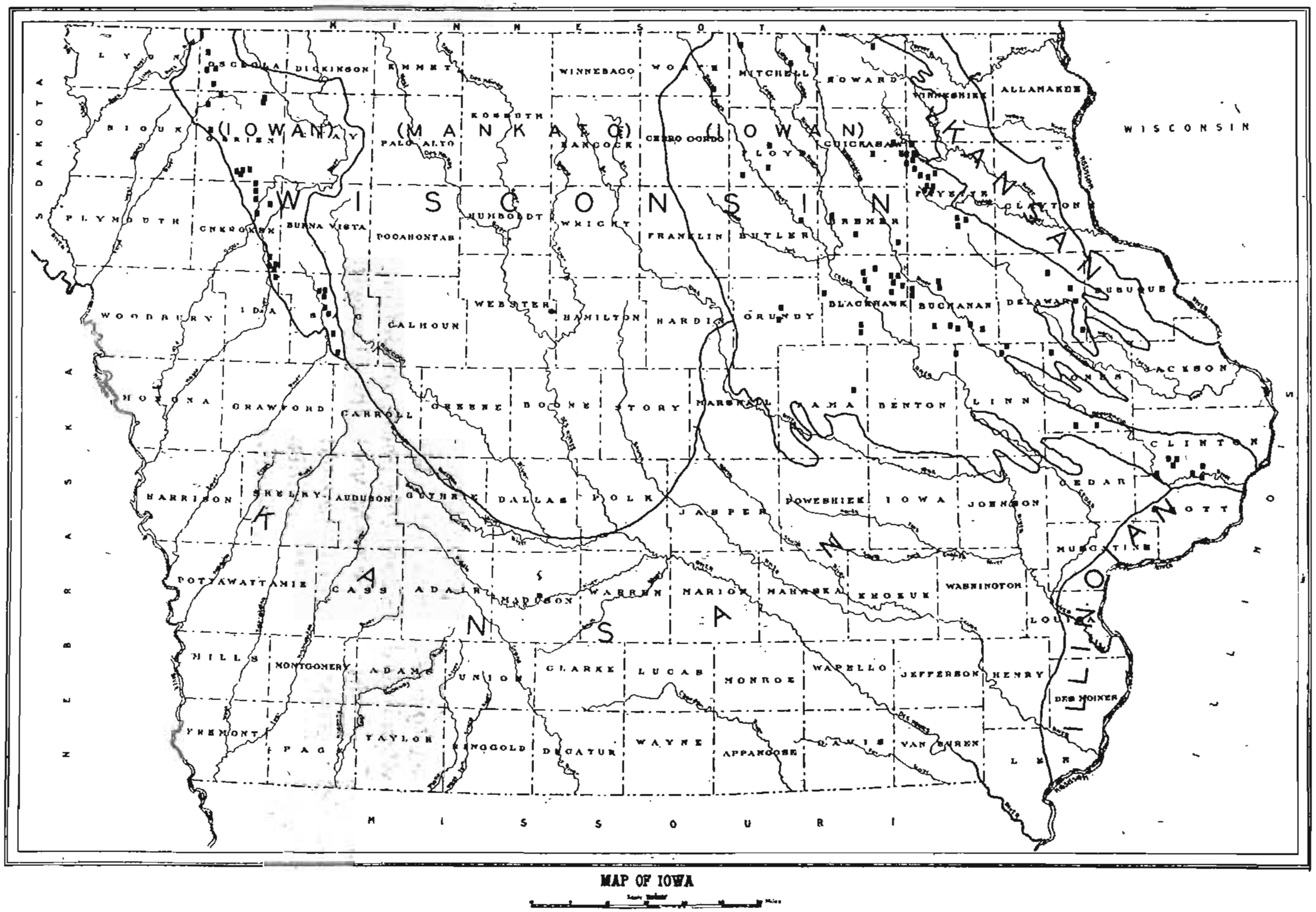

Figure 38. Map of Iowa showing the locations of Iowan upland gravels.

irregularities between the two types of till but these are not greater than are commonly found within samples of the same type. Furthermore, any variations are not constant within different samples.

The lithology of the unoxidized and unleached till is the same as that of the oxidized and unleached till since the only difference in these tills is the oxidation of the iron compounds which does not change the rock content.

The shapes of the grains have been unchanged by weathering processes and thus represent the shapes at the time of deposition. The results of analyses of the size grades comparable to those used in the analyses of the Illinoian unoxidized and unleached till in figure 7, page 35, are almost identical to those of the Illinoian.

Iowan Gravels

The melting Iowan glacier deposited two general types of gravel which are found in many places within the area of the Iowan drift. These deposits, along with all other known Pleistocene gravel deposits of importance in the state, have been the subject of an exhaustive study by Kay and Miller.[87] The discussion of the Iowan gravels which follows has been taken largely from their report.

The Iowan Upland Gravel

Kay and Miller have differentiated the Iowan gravels into Iowan upland gravel and Iowan terrace gravel, and on page 121 of the report cited above have described the upland phase as follows:

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

Figure 38 is a map showing the location of Iowan upland gravels.

Since these gravels were deposited contemporaneously with the Iowan till, changes in them comparable to the changes noted in the Iowan till have taken place. Leaching has occurred to an average depth of from 4 to 6 feet. Secondary calcium carbonate in the form of concretions and cement has been deposited below

[87]Kay, G. F., and Miller, Paul T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, pp. 119-162, 1941.

the leached phase. Oxidation has stained the zones above the unaltered material to various shades of yellow or brown, the color being variable in keeping with the variation in the percentage of iron compounds inherent or carried into the gravel.

Stratification is apparent in most of the upland gravel deposits, but as is to be expected in gravels deposited directly by the glacier, there are such irregularities as clay-balls, boulders, inclusions of Iowan till or older material, etc. The gravels show considerable size range, most of the material being smaller than 6 centimeters in diameter, but there are many cobbles and boulders distributed through the gravel, some having an average diameter of more than 80 centimeters.

The percentage of each different size grade in the various exposures, as determined by mechanical analysis, is shown in figure 39. The lithology of the pebble constituency of the same exposures falling within the 16 to 32 millimeter size range is shown in figure 40. These gravels may be found with a covering of Iowan till, Peorian loess, or both, or may lie at the surface. Usually they are thin, but have been found with a thickness of 15 or more feet.

A typical exposure of Iowan upland gravel occurs in a pit in the SW¼ sec. 22, Cedar Falls Township, (T. 89 N., R. 14 W.), Black Hawk County, 2 miles west of Cedar Falls. The gravel is exposed along the hillside in an area having a relief of about 75 feet. The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, oxidized, and filled with humus which colors it to chocolate brown	2	
Iowan glacial substage:		
Pebble band, Iowan, on the surface of the Iowan till		1
Till, oxidized to the usual buff color, leached to a depth of about 3 feet, several large boulders with the largest having a diameter of about 8 feet	12	
Silt and fine sand, unoxidized, leached and well stratified in thin horizontal beds, grading into gravel at the base	1	
Gravel, well stratified, unleached, oxidized to a medium brown, pebbles show some striations and some stream wear	10	
Till, gray on the surface when dry, blue-black when wet, unleached and unoxidized, contains boulders	4	

Calcium carbonate in the loess and Iowan till above the gravels has been leached to a depth of a little more than 5 feet, which is about the average for Iowan materials. There is some disintegration to be seen in the crystalline pebbles. The material is largely sand and gravel finer than 3 centimeters in diameter. Samples

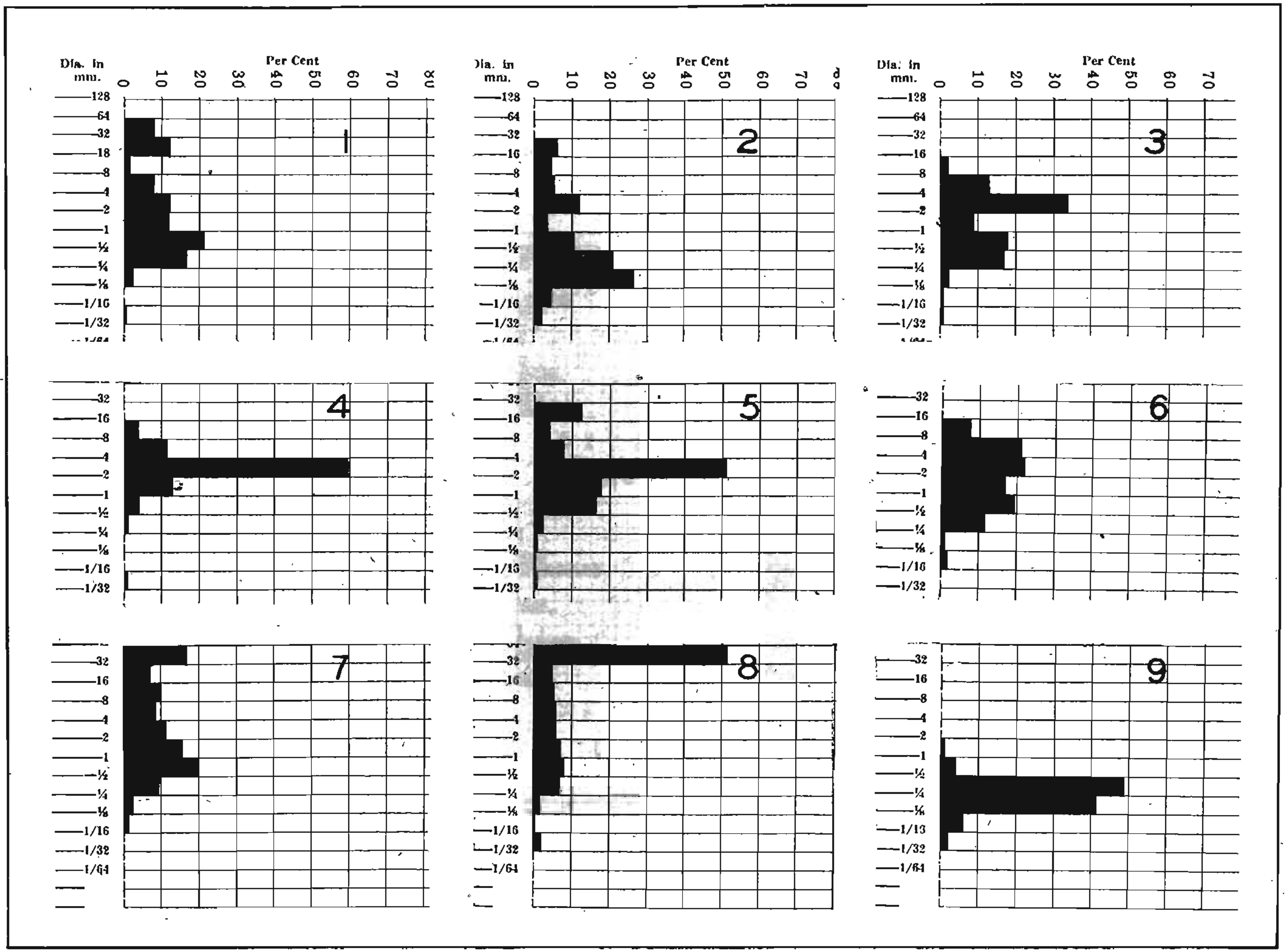

Figure 89. Graphs showing the mechanical analyses of Iowan upland gravels.

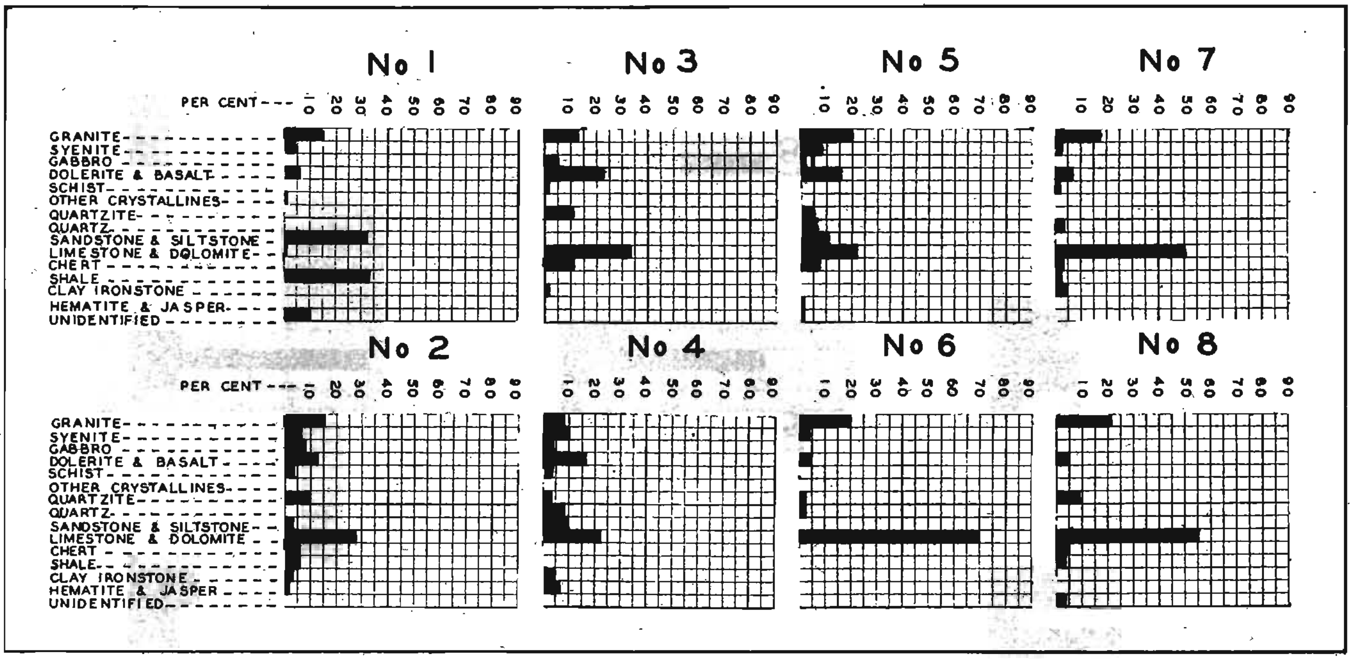

Figure 40. Graphs showing the lithological analyses of Iowan upland gravels within the size range 16 to 32 millimeters in diameter.

nos. 1 of figures 39 and 40 represent the size percentages and lithologic content respectively of the section.

Another exposure of Iowan upland gravel is in the NE¼ sec. 35, Wayne Township, (T. 100 N., R. 15 W.), Mitchell County, about one-half mile east of McIntire. These gravels overlie both Kansan gravel and Loveland loess. Above the gravel deposit lies Iowan till with a maximum thickness of 5 feet, here unleached in the basal part.

The Iowan gravel is here 2 to 5 feet thick, oxidized light brown, and slightly adherent with iron oxide. It is horizontally bedded in general, but with poor sorting, with some steeply dipping beds. In size the gravel is mostly finer than 5 centimeters in diameter, but cobbles are found ranging up to 15 centimeters in diameter, some of which show striations. The size grade percentages and pebble lithology of this section are graphically shown in nos. 3 of figures 39 and 40.

In northwestern Iowa, gravels and till of Iowan age were described in great detail by Carman.[88] One of the finest exposures of gravels in the Iowan till to be found in the state is described in his report as follows:

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

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

Carman's detailed sections which were included with the discussion of this locality indicate two, three, and four important gravel horizons which, to all appearances, were not continuous. All the gravels as well as the interbedded till are fresh. Clay-balls which occur in great profusion in the gravel lenses, seem to

[88]Carman, J. E., Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, pp. 21-187, 1931.

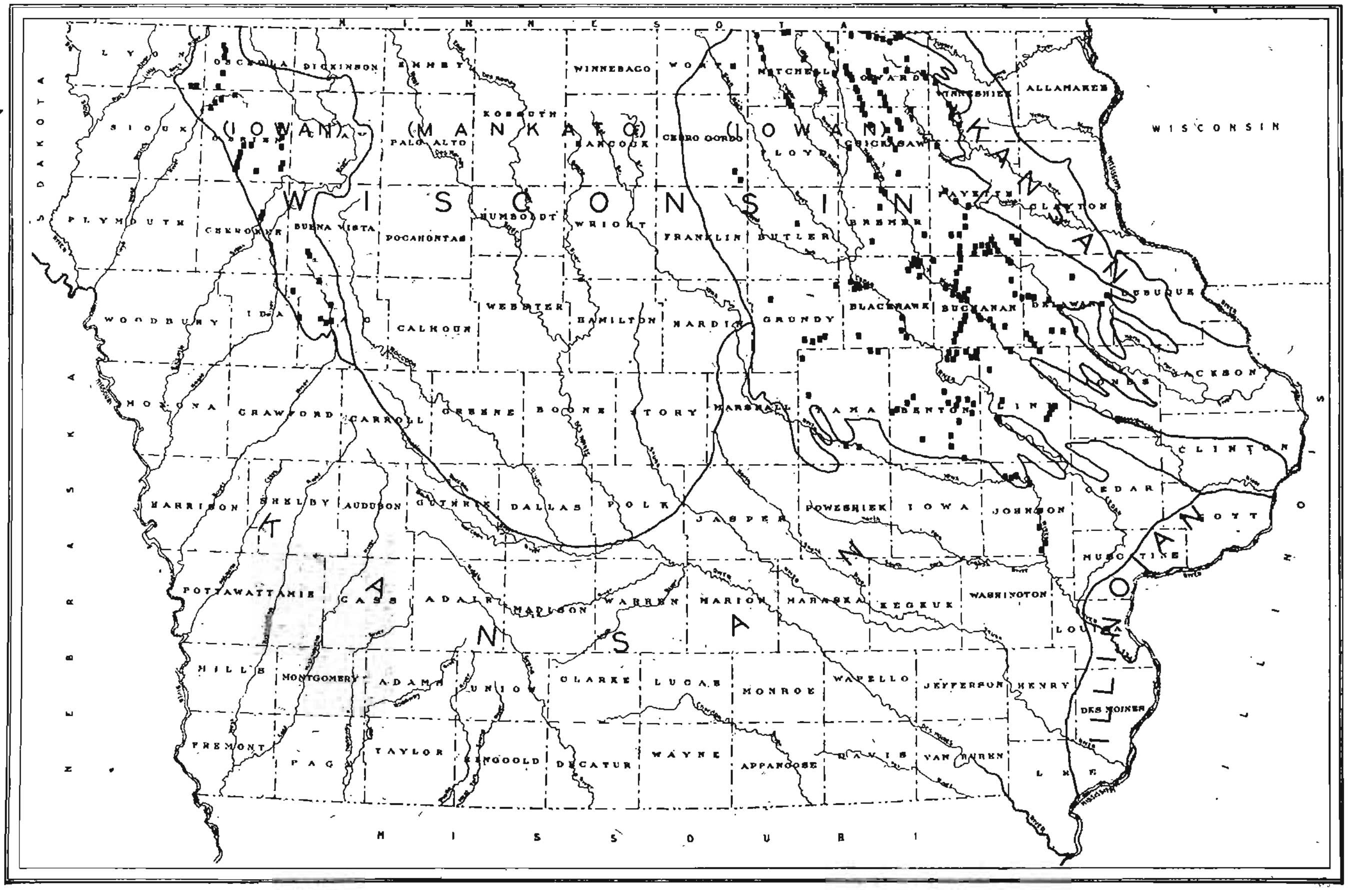

Figure 41. Map of Iowa showing locations of Iowan terrace gravel exposures.

indicate that the materials had not undergone great transportation before deposition, as the clay masses, even though frozen, would not have survived the wear of any considerable transportation. As this location is near the western margin of Iowan ice extension, this interphasing of Iowan till and gravel would seem to reflect the fluctuating action of the glacier terminus, with successive advances and retreats depositing till and gravel in turn.

The age of the Iowan upland gravel may be determined by the relation of the deposits to the Iowan drift and by the amount of alteration the gravel has undergone where the cover conditions are known. All of the deposits are closely associated with the till, either as masses within the till, or as outwash on its surface.

The Iowan Terrace Gravel

Terrace gravel of Iowan age occurs quite generally in the valleys of streams which flow within, or head within the area covered by the Iowan drift (fig. 41). They have been interpreted by Kay and Miller[89] as follows:

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

Since the deposition of the Iowan terrace gravel, the streams have in general entrenched themselves in the gravel fillings,

[89]Kay, G. F. and Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, p. 144, 1941.

leaving remnants of the gravel floor as terraces which in some localities are as much as 100 feet above the present stream level. A typical exposure of Iowan terrace gravel is shown in figure 42. The gravel deposits may lie upon Iowan or older till, and may be overlain by coarse, unstratified, sandy silt with pebbles in the basal part, or by Peorian loess, or both. The thickness of the overburden averages about 3 feet, but ranges from 6 inches to more than 6 feet. Nowhere has there been found evidence of a time interval between the deposition of the gravel and that of the overlying material.

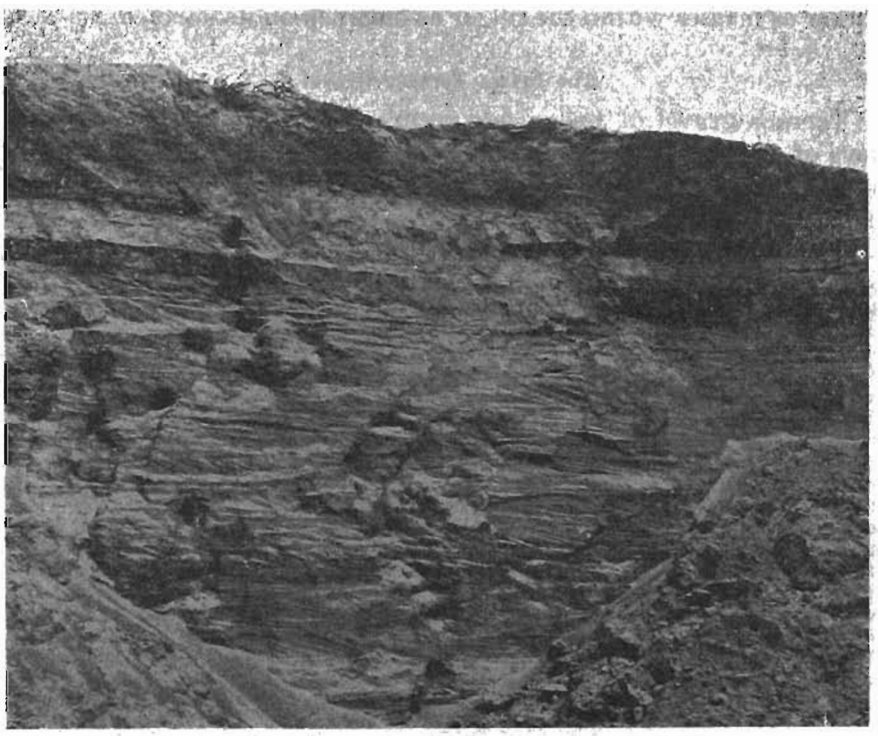

Figure 42. Terrace gravel of Iowan age near Iowa City, Johnson County.

As with the Iowan upland gravel, changes due to weathering have occurred in the terrace gravel, but with greater variation of depth. This variation is thought to be due not primarily to differences in the amount of leaching, but to lithology, topographic position, and subsequent erosion. In those deposits where the lith-

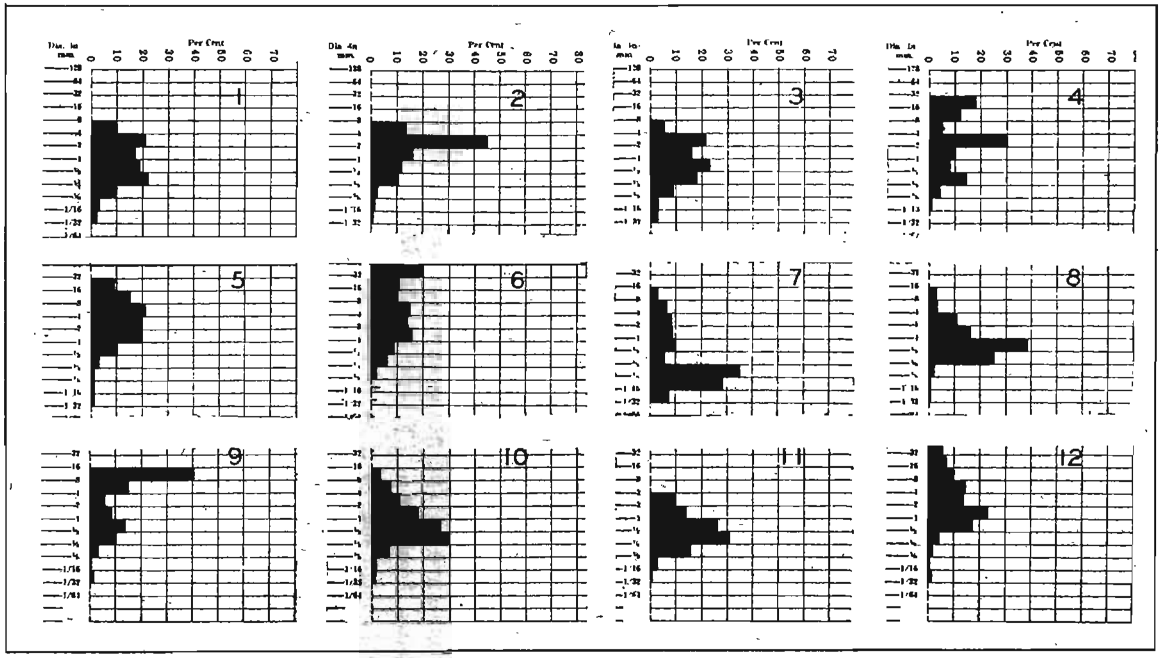

Figure 43. Graphs showing mechanical analyses of Iowan terrace gravel.

ology and texture of the terrace gravel is comparable to the upland gravel, the depth of leaching is 4 to 6 feet, as in other materials of Iowan age. The slightly greater depth of leaching found in many of the terrace deposits may be due to greater freedom of ground-water circulation.

The terrace gravel appears fresh, and only occasional cobbles or boulders show any disintegration. No cementation was noted in any of the exposures. In grade size, the terrace gravel is mostly sandy, as is shown in the mechanical analyses of figure 43. The lithology of the pebbles occurring in the 16- to 32-millimeter range in diameter is shown in figure 44. The lithology of the terrace gravel differs from the upland gravel in lacking the clay-ball content, and in having a higher content of siliceous and resistant igneous rocks. The color varies from gray unoxidized gravel to dark brown resulting from iron oxide stain. The gravel is normally well stratifed in horizontal beds, and usually contains two members, a finer, more sandy phase below, and a coarser, more gravelly phase above. The first is rarely used for commercial purposes.

In the detailed work of Kay and Miller on the gravels of the state, it was found that the Iowan terrace gravel could be roughly separated into deposits of a (1) highly siliceous character; (2) deposits with intermediate calcareous and siliceous content; and (3) deposits of a highly calcareous nature.

A good exposure of the noncalcareous type occurs in the NW¼ sec. 2, Jenkins Township, (T. 100 N., R. 15 W.), Mitchell County. The gravel is exposed to a height of 30 feet above the level of a tributary of Wapsipinicon River, one-half mile south of McIntire. Fifteen feet of unslumped gravel is exposed. The overburden consists of sandy, loess-like silt, ranging from 1 to 2 feet in thickness.

The gravel is oxidized to a light or reddish-buff color. No carbonates, either primary or secondary, are found. The gravel is fresh in appearance. The upper 5 feet is largely sand in thin horizontal beds. The lower material is also fine, but with a greater percentage of pebbles and lenses of coarse material. Nothing within the exposure was found to exceed 3 centimeters in diameter, and less than 4 percent is larger than 8 millimeters in diameter. The size grade percentage and the lithology of this section are given as graphs no. 1 in figures 43 and 44.

The intermediate type of Iowan terrace gravel which contains a considerable amount of both siliceous and calcareous material,

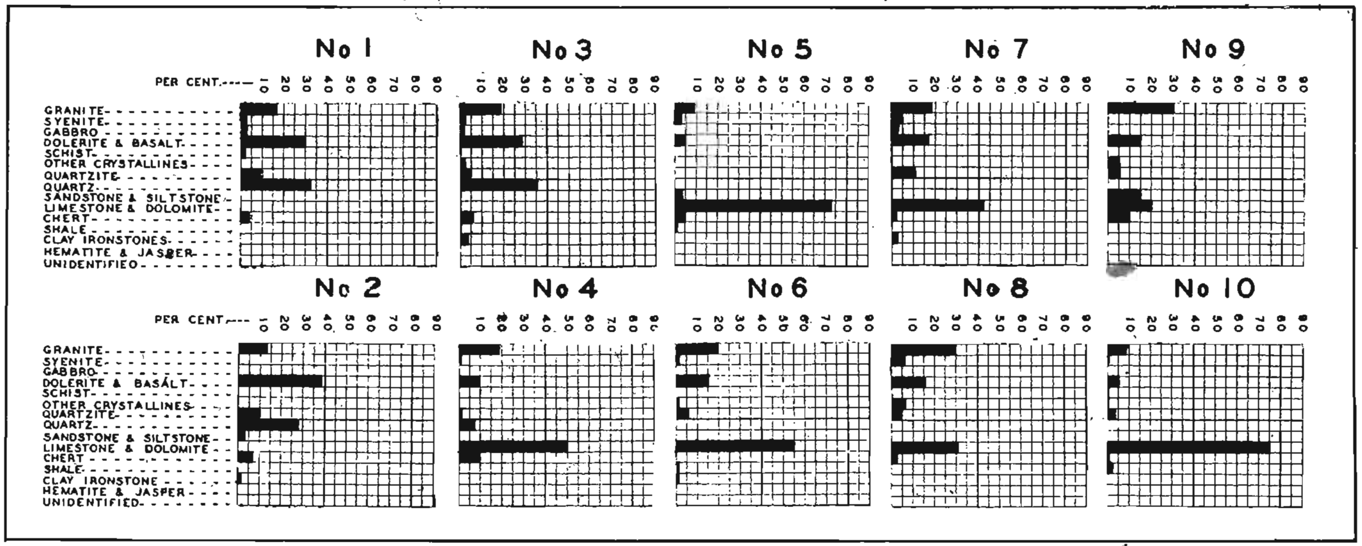

Figure 44. Graphs showing the lithological analyses of Iowan terrace gravel within the size range 16- to 32-millimeters in diameter.

is the most common type of deposit. The gravel is normally oxidized buff colored, and leaching has removed the carbonates to a depth of 5 to 6 feet. The gravel is fresh in appearance.

In the SE¼ sec. 35, Colfax Township, (T. 88 N., R. 17 W.), Grundy County, along Black Hawk Creek south of Holland, this type of gravel is exposed in a terrace standing 18 feet above the stream. Six feet of gravel is overlain by 4 feet of Peorian loess. The gravel is light buff in color. Leaching has removed the carbonates from the 4 feet of overlying loess and from the upper 1 foot of gravel. Below the leached zone are many concretions of secondary lime and pebbles of limestone and dolomite. The gravel is poorly sorted, with a textural range up to 3 centimeters, but mostly below 1 centimeter in diameter. The bedding is horizontal in general, with some cross bedding. The textural range and lithology of this exposure are graphically shown in graphs no. 7 of figures 43 and 44.

Highly calcareous terrace gravel of Iowan age is fairly common in both northeastern and northwestern Iowa. The limestone and dolomite content usually occurs as large angular fragments up to 30 centimeters in diameter.

A good example of this type of gravel is in a gravel pit in the east side of Sibley in the NW¼ sec. 18, East Holman Township, (T. 99 N., R. 41 W.), Osceola County, near the valley of Otter Creek. Here the terrace lies approximately at the upland level and several gravel pits have been opened near the stream, both east and south of Sibley. Carman[90] studied some of the older of these pits in detail.

A new exposure in this terrace shows 20 feet of highly iron-stained, dark-buff gravel, uniform in oxidation to the bottom, although Carman's sections of nearby pits show a considerable variation in oxidation with depth. What disintegration is apparent in the pebbles occurs principally in the gray shale content. Leaching has occurred in the 3 feet of typical Peorian loess overburden, but none of the gravel is leached, and oxidized and unleached till, presumably Iowan, underlies the gravel. The major bedding of the gravel is horizontal, but thinner cross-bedded phases show dips at various angles. The lenses and pockets within the gravel are almost entirely of gray shale. The textural range and lithology of the pebbles are given in the analyses listed as graphs no. 5 in figures 43 and 44.

[90] Carman, J. E., Further studies on the Pleistocene geology of northwestern Iowa: Iowa Geol. Survey, vol. 35, pp. 141-144, 1931.

The age of the gravels described in the sections given above cannot be determined with the same definiteness as certain other Pleistocene gravels of the state may be dated. They are known to have been deposited in valleys formed in the post-Kansan gumbotil pre-Iowan interval, and in such places as they have been observed lying on, or interbedded with Iowan till, are Iowan in age. Where the gravels are overlain by Peorian loess, no evidence of weathering of the gravels, or any transition zone between the two indicating an interval of time, is to be seen. However, as has been stated, a part of the gravel may be Loveland in age, either rehandled by Iowan meltwater during Iowan glaciation, or as an indistinguishable part of the terraces which received their final deposits in Iowan time.

Fossils of late Pleistocene age have been found in the Iowan terrace gravel, and a few of these principally the vertebrate fauna, have been mentioned by Carman.[91] The junior author made a brief investigation of the terrace levels in several of the western border counties, in an attempt to determine the southern extent of these Iowan fossil-bearing terrace gravels. Some of the vertebrate forms brought from this region to early paleontologists and ascribed by them to deposits then thought to be Aftonian gravels, would now seem to be more representative of more advanced types which are found in the Iowan gravel terraces.

Thickness of the Iowan Drift

With the possible exception of a narrow overlap of the Iowan on Illinoian drift in northern Scott County, the Iowan drift lies on a region previously covered by Kansan drift. Hence the materials of the Kansan drift lay at the surface in the Iowan area, subject to the various processes of weathering and erosion for the great length of time represented by the Buchanan interval. This interval, named by Calvin for deposition or weathering in the Iowan area occurring on Kansan drift before Iowan glaciation, includes the long Yarmouth interglacial, the Illinoian glacial, and the Sangamon interglacial ages, and represents in actual time, more than half of the estimated duration of the Pleistocene period in Iowa. Therefore, the surface over which the thin Iowan glacier moved was a region with well developed erosional features. By Iowan time, the surface had been denuded in places to expose bed-

[91] Carman, J. E., *op. cit.*, pp. 164-166.

rock or its weathered derivatives, Nebraskan drift, Aftonian deposits, or various phases of the Kansan drift. In other places, the till or bedrock materials were covered in Sangamon time by Loveland loess.

The topography of the whole was typically erosional, with marked stream dissection forming broad, mature valleys with gentle and smooth slopes. Areas of undissected upland—the Kansan gumbotil plain—were present in places at the time of Iowan ice invasion. The landscape was without great relief. Only locally did small outcrops of bedrock form small gorges along the otherwise mature drainageways.

Upon this erosional topography which was developed on Kansan and older drift materials during the Buchanan interval, the Iowan drift was spread as a thin mantle, partially filling the valleys, smoothing the relief, and exhibiting only occasional constructive features entirely Iowan. This veneering of the mature Kansan landscape by the thin but distinctive Iowan drift gave the "gentle rolling" topography which is so characteristic of a large part of the northeastern Iowan portion of the state. Presumably this same "gentle rolling" drift-mantled erosional topography extended on west and characterized the Iowan drift surface now covered by the Mankato lobe of the Wisconsin stage though northwestern Iowa gives evidence of upward warping which has resulted in extensive erosion of the drift materials. This, and the covering of loess of Peorian age which was blown over the triangle of Iowan drift lying west of the Mankato lobe, has somewhat modified the expected similarity to the eastern part of the Iowan lobe in northeastern Iowa.

In view of these existing field relations, it has been difficult to get a true average for the thickness of the Iowan drift. Calvin,[92] whose careful observations and long familiarity with the Iowan drift have kept his reports on this subject as important references today, reported neighboring sections with depths ranging from 1 to 30 feet. Calvin suggested that large areas of the drift would average less than 10 feet in thickness.

The thickest sections of Iowan drift are in the constructional areas of the drift margin. Such a section is along the north line of sec. 16, Windsor Township, (T. 94 N., R. 9 W.), Fayette County. This cut is in the marginal moraine, and the hills just south of the

[92]Calvin, Samuel, The Iowan drift: Geol. Soc. America Bull., vol. 10, pp. 112-113, 1900.

cut which exposes Iowan till lying on Kansan gumbotil, rise 37 feet above the gumbotil level. This thickness is all Iowan till.

Near Clarence in Massillon Township, (T. 82 N., R. 1 W.), Cedar County, and along the south edge of the Clinton lobe of the Iowan drift, the Iowan till attains a thickness of about 45 feet, this depth being based on the height of the Iowan till surface above the level of the underlying Kansan gumbotil.

An even thicker section of Iowan drift is in sec. 19, Beaver Township, (T. 89 N., R. 16 W.), Grundy County, about 2 miles north of Fern. Kansan gumbotil is exposed in a cut along the north part of the road between sections 19 and 20. To the southwest of this cut there is considerable relief in the Iowan till, measuring about 60 feet from the gumbotil level to the top elevation of the Iowan knoll.

Another section, previously described, which shows an unusual thickness of Iowan drift is located nearly in the center of the northeastern Iowan drift region. It is in a gravel pit about 2 miles southwest of the Iowa State Teachers College at Cedar Falls, in the NE¼ sec. 27, Cedar Falls Township, (T. 89 N., R. 14 W.), Black Hawk County. The section exhibits 23 feet of Iowan till, in which all of the Iowan till phases are represented. The base was not exposed.

However the great majority of Iowan till exposures range from 1 to 7 or 8 feet, and the average thickness of the till probably does not exceed 10 feet. The extreme thinness of the till of a glacier as extensive as the Iowan is known to be, coupled with the digitate form of the southeastern margin of the drift and the Kansan islands within the till border, all demand an explanation which has not as yet been adequately formulated. That the till is present; that it manifests certain conditions of weathering and erosion; that its lobate boundaries are where they have been mapped; that on its surface are many large boulders; that the till thickness is no thicker than is shown by the average of the great number of known sections, widely distributed;—all these are facts of observation. Such a combination of features will continue to invite satisfactory interpretations from all students of glacial phenomena.

THE PEORIAN INTRAGLACIAL SUBAGE (SUBSTAGE)

Classification of Peorian intraglacial subage (substage)
The Peorian loess
Distribution and topographic expression of the Peorian loess in Iowa
Loess mantled erosional topography

Loess depositional topography
Typical sections of the Peorian loess in Iowa
Characteristics of the Peorian loess
General characteristics
Mechanical analyses
Mineral analyses
Chemical analyses
Fossils in the Peorian loess in Iowa
Vertebrates
Invertebrates
Depth of leaching in the Peorian loess
Thickness of the Peorian loess in Iowa
Comparison of the Peorian loess with the Loveland loess

Classification of the Peorian Intraglacial Subage (Substage)

In the classification of the Eldoran epoch (series) of the Mississippi Valley, Kay and Leighton include two ages (stages), the Wisconsin glacial age (stage), and the Recent interglacial age (stage). The Wisconsin glacial age (stage) includes four subages (substages), the Iowan (Oldest Wisconsin), the Tazewell (Early Wisconsin), the Cary (Middle Wisconsin), and the Mankato (Late Wisconsin). In this classification the name Peorian does not appear. Leighton and his associates had shown that there was continuous deposition of loess from Iowan time until after Early Wisconsin time, and furthermore that the interval heretofore called Peorian was so short as to necessitate its elimination as an interglacial age from the classification of the Pleistocene in Illinois.

In Iowa the record of the Wisconsin age is less complete than in Illinois. Here the Tazewell and Cary substages of the Wisconsin stage are absent. The Iowan substage is separated from the Mankato substage by a widespread loess which for many years has been mapped as Peorian loess, and the time of deposition of the loess and the time of weathering of the loess prior to the deposition of the Mankato drift has been called the Peorian intraglacial age.

In the revised classification of the Wisconsin age Kay and Leighton[93] make the following statement with regard to the usage of the name Peorian in Illinois and in Iowa:

> "The name Peorian will continue to be used in Iowa for the widespread loess which lies on the Iowan drift and around its border, and beneath the Mankato (Late Wisconsin) drift; and in Illinois for the widespread loess which lies above the Late Sangamon loess outside of the Tazewell drift. Within the border of the Tazewell drift the loess which immediately underlies it may be called Iowan, as originally proposed, and the loess which overlies it, the Tazewell loess. These two loesses are indistinguishable outside of the Tazewell drift border and compose the Peorian loess."

[93]Kay, G. F., and Leighton, M. M., Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-673, 1933.

The Peorian interval in Iowa is now interpreted to be an intraglacial subage rather than as previously, a short interglacial age. As formerly, the Peorian interval will include the time of deposition of the widespread loess which is interpreted to be Iowan in age and the time during which this loess underwent weathering prior to the deposition of the Mankato drift. In Illinois the Peorian loess includes loess of Iowan age and of later Tazewell age. Thus far it has not been possible to differentiate the two loesses outside the Tazewell drift border. In Iowa, although the Peorian loess appears to be a unit formation of Iowan age, it may be that future investigation may be able to show that the upper part of the loess is as young as the Tazewell loess.

The Peorian Loess

McGee,[94] in his final report on northeastern Iowa, and in earlier papers, interpreted the loess to be aqueous in origin. He correlated the widespread loess deposits in northeastern, southern, and southeastern Iowa with his Upper Till, calling them loess-drift or drift-loess. After the Upper Till had become known as Iowan till the loess related to it was called Iowan loess. This was the usage in Iowa and in Illinois.

The name Peorian was used first by Leverett[95] who applied it to the weathered zone at the contact between the Iowan loess and the Wisconsin till in Illinois. In an exposure—the Farm Creek Section—east of Peoria, there was evidence of an interval of weathering between the time of deposition of the loess, which was correlated with the Iowan till, and the Shelbyville till sheet, which appeared to be the earliest of the Wisconsin series. The interval was named the Peorian interglacial interval.

Calvin in 1899,[96] accepting the aqueous theory of origin of loess made the following statement:

"The geographical distribution and physical characteristics of the typical loess of northeastern Iowa suggest genetic relationship with the Iowan till. That it was in some way derived from the till when the Iowan ice invasion was at its maximum is indicated by many lines of evidence. The main body of the loess was all extra-marginal. Over no considerable area is typical loess ever found resting on Iowan drift. It lies thickest just at the margin of the region occupied by Iowan ice at the time of its maximum development, and is spread widely but not uniformly, over the extra-marginal space to distances at present undetermined. Loess, or a product resembling loess,

[94]McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey 11th Ann. Rept., pp. 199-586, 1891

[95]Leverett, Frank, The Peorian soil and weathered zone (Toronto formation?): Jour. Geology, vol. 6, pp. 244-249, 1898.

[96]Calvin, Samuel, The Iowan drift: Geol. Soc. America Bull., vol. 10, pp. 107-120, 1899.

was developed in connection with more than one drift sheet and it is possible that the Iowan loess blends into loess-like deposits of different age in some portions of the extra-marginal territory."

A few years later Shimek[97] presented evidence in support of the interpretation that the loess which was being called Iowan loess was not aqueous but chiefly eolian in origin, and that the fossils of the loess indicated that the loess was not glacial in age but was deposited after the retreat of the Iowan ice sheet and hence was interglacial in age. The eolian origin soon was accepted quite generally and the loess was interpreted to be not contemporaneous in age with the Iowan drift but somewhat later in age than the Iowan. With this change in interpretation, the loess began to be called Peorian loess because it had been deposited in the interglacial age between the Iowan and Wisconsin glacial ages. This application of the Peorian although not in accord with the meaning given to it originally by Leverett was adopted generally and apparently without adverse criticism. This was the view of Calvin[98] in 1911. He states:

"The earlier view was that the loess was deposited at the time of maximum development of the Iowan glaciation, when the Iowan area was still covered by ice. The only modification of that view at the present time is that loess deposition took place after the Iowan ice had retreated to a greater or less extent, after an interglacial interval had actually begun. By such retreat extensive mud flats were left, and as these dried before becoming covered with vegetation, strong winds coming, probably, from the ice fields farther to the north, carried fine sand and dust from the bare surfaces and deposited them beyond the edge of the Iowan area, out upon the old eroded Kansan. . . . . The genetic relation of the loess to the Iowan drift is not so very unlike the corresponding relation of the Buchanan gravels to the Kansan; and so far as the genetic relationships are concerned, there has been no abandonment of the view originally proposed.

"The color, composition, and calcareous content of the Iowan loess are in perfect accord with the hypothesis just expressed; its geographic distribution around the lobed margin of the Iowan area agrees also with the view; the great thickness of loess in or at its inner margin, and its thinning out with increasing distance from the source of supply, corroborate all the other lines of evidence; while the great amount of eolian sand associated with it in a narrow belt surrounding the lobes of Iowan drift lends additional support. The Missouri river loess and all other loess deposits which have evidently been derived from the broad flood plains of nearby rivers, have a similar distribution relative to their source; they are thickest and coarsest near the gathering ground and become thinner as the distance from the base of supply increases. All the facts connected with the origin, composition, and distribution of the loess are perfectly explicable without resorting to the hypothesis that 'a considerable part was derived from the great plains east of the Rocky Mountains.' Studies in the field afford overwhelming evidence that, genetically and geographically, the Iowan drift has very intimate relations to certain bodies of loess."

[97]Shimek, Bohumil, Loess and the Iowan drift: Iowa Univ. Studies in Nat. History, vol. 5, pp. 356-368, 1904.

[98]Calvin, Samuel, The Iowan drift: Jour. Geology, vol. 19, pp. 601-602, 1911.

This was also the view of Alden and Leighton in their report on the Iowan drift in the 1915 Annual Report of the Iowa Geological Survey.

Leverett[99] in a paper published in 1926 stated:

"Features of the Iowan drift and its relations to the loess seem to demand further critical field study."

His viewpoint as expressed in this paper was that the Iowan drift should be correlated in age with the Illinoian drift and that a pebble band on the Iowan drift and beneath the loess is the result of slope wash rather than of wind action. He thinks that a great length of time was necessary for the development of this pebble band, and hence the loess overlying the pebble band must be very much younger than the Iowan till upon which the pebble band lies.

Kay[100] replied to the arguments of Leverett as has been stated somewhat fully already on pages 96 to 97. Leighton eliminated the Peorian from the classification of the Pleistocene in Illinois. His evidence for this interpretation was that the Peorian loess had been deposited continuously from Iowan time until after Early Wisconsin time and hence there was no distinct Peorian interval. In Illinois, as previously stated, Peorian is now used for the widespread loess which lies outside the Tazewell border, and in Iowa the Peorian is used for the widespread loess of Iowan age and for the time of weathering between the deposition of the loess and the Mankato drift.

When the fossils of the Peorian loess are discussed it will be shown that the fossil evidence is now interpreted to be consistent with a glacial origin of the loess rather than with an interglacial origin.

The history just outlined shows clearly that the many persons who have studied the Peorian loess have differed in their interpretation with regard to its origin and age. At present there is agree ment as to the eolian origin of the loess but some difference of opinion continues regarding its relation to the Iowan till.

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[99] Leverett, Frank, The Pleistocene glacial stages: Were there more than four? Am. Phil. Soc. Proc., vol. 65, no. 2, 1926.

[100] Kay, G. F., The relative ages of the Iowan and Illinoian drift sheets: Am. Jour. Sci., vol. 16, pp. 497-518, 1928.

Kay, G. F., The relative ages of the Iowan and Wisconsin drift sheets: Am. Jour. Sci., vol. 21, pp. 158-172, 1931.

Distribution and Topographic Expression of the Peorian Loess in Iowa

The Peorian loess of Iowa has not been distributed evenly over all of the state. Due to the localized nature of the two main source areas of the loess material, namely the valley of the Missouri River and the Iowan drift sheet, certain sections of the state have received a considerable thickness of the windblown material, while other regions more removed from the important sources, received only enough to thinly mantle the surface of the drift or bedrock.

This difference in loess thickness has resulted in two main types of loess typography over the state; one, the so-called loess mantled erosional topography which presents an old erosional topography which has been modified but not obliterated by the loess mantle; and second, loess depositional topography, exhibiting a topography with forms attributable entirely to the loess, the former surface having been buried too deeply to lend expression to the present surface (see fig. 27, page 104). These two principal types of loess topography will be described briefly.[101]

Loess Mantled Erosional Topography

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

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

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

[101]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, pp. 54-58, 63-65 1929.

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

The prevailing position of the loess in the Crawford area is on the tops of hills and on the upper parts of the slopes. Thinner loess extends into and across the valleys, giving the appearance of loess built topography, but numerous road cuts and some exposures along the valleys show clearly that the hills have cores and that the loess in the valley bottoms is thin. On the higher slopes the loess is from 10 to 30 feet or more in thickness, as illustrated by figure 45 whereas on the lower slopes the loess is in most places less than 10 feet, locally only 3 or 4 feet in thickness. The abundant loess in the upper slopes in many places has a definite relation to the drift core. The crest of the hill, due to loess deposition, has migrated to the eastward with the loess asymmetrically distributed over the drift. It is thicker on the east side than on the west side. This is a normal relationship in this region. The loess, a wind-blown material, was carried from the west, and hence the windward slopes have had deposited upon them less of the loess than was deposited on the leeward slopes. Thus, coincident with increase in relief by loess deposition the slopes were modified. The eastern slopes particularly show the effect of migration of the crests of the hills without equivalent shifts of the valley bottom. Western slopes may show slight modification or if the increase of relief by loess deposition is relatively great when compared with the drift relief, the westward slopes may be appreciably steepened, as seen in figure 46. The hill and valley modifications are not everywhere uniform in character nor are they of the same kind. The western part of the Crawford area has more loess, and hence is more modified than the eastern part. This is as would be expected since it is nearer the Missouri River Valley, the chief source of loess supply.

The somewhat heavy loess over the Crawford area is of Peorian

Figure 45. Divide cut between Aspinwall and Manilla, Crawford County, showing about 25 feet of Peorian loess overlying Kansan drift.

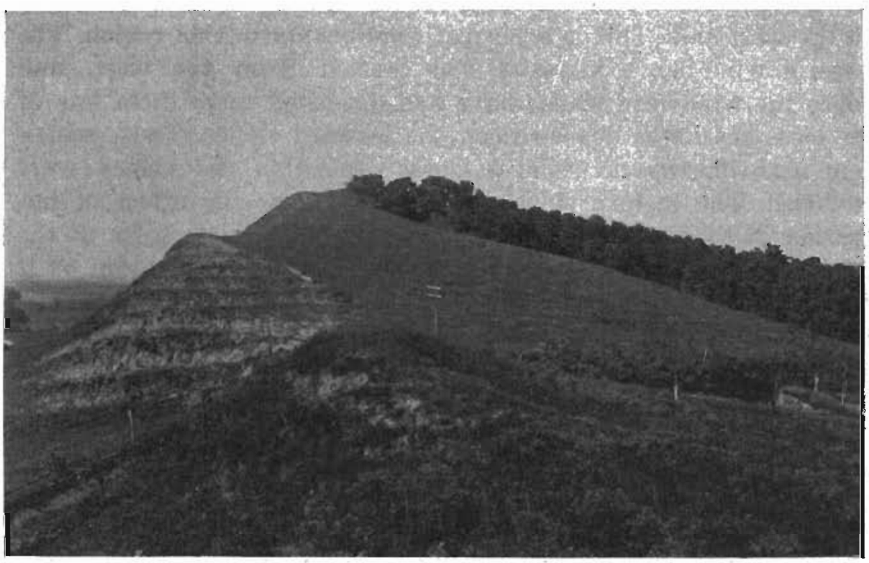


Figure 46. Looking north along loess bluffs from top of ridge south of Pisgah, Harrison County.

age. There are beneath this younger loess an older loess and a series of silts and sands which lie unconformably upon the eroded surface of the Kansan gumbotil plain, and which contribute in a minor way to the topographic development of the area. These older deposits, which in part at least are correlated with those known to be younger than the Illinoian, and older than the Iowan, constitute the Loveland loess and associated silts and sands.

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

The reliefs of the Cedar and Jackson areas differ somewhat. The maximum relief of the Jackson area is about 400 feet, whereas the relief of the Cedar area is only half as much. The proximity of the Jackson area to the Mississippi River, and the underlying indurated rocks account for the greater relief in this area. The indurated rocks in the Cedar area have but little effect upon the topography.

The prevailing features of the Cedar and Jackson areas are loess-built structures on the hill slopes and thick loess deposits bordering the erosion carved valleys. The modifications of the erosion slopes take the form of rolling hills—dune-like accumulations of loess and sand. The total relief of the surface is increased by the presence of the loess, but the chief result has been the multiplying of slopes together with the steepening of the slopes along the river valleys. On the uplands or divides the loess is in most places thin, perhaps not more than 10 feet thick. These divide areas are gently rolling, conforming to the major slopes of the underlying erosion surface, but have their own distinctive topographic expression as seen in the variations in the convexity of the different parts of the slope and in the minor surface irregularities.

Near the main stream courses the loess is thicker than on the divides, in many places reaching a thickness of 30 or 40 feet or even more. Here the underlying erosional drift topography has been distinctly modified. Slopes east of the valleys have undergone greatest modification, indicating the effect of the prevailing westerly winds. The crests of the hills along the valleys are capped asymmetrically by loess—thickest on the eastern leeward slopes. The hill slopes are broken into a series of undulating convex and concave curves. The shoulders of the hills are rounded by loess with accompanying steepening of the lower slopes.

Loess Depositional Topography

A narrow strip 3 to 20 miles in width bordering the flood plain of Missouri River has loess depositional topography. The area includes parts of Woodbury, Monona, Harrison, Pottawattamie, Mills, and Fremont Counties. To the west is the Missouri flood plain; to the east is the loess mantled erosional topography of the Crawford area already described.

The area of loess depositional topography has a greater thickness of loess than the area of loess mantled erosional topography. Here, a considerable part of the relief is in loess, as a thickness of 90 feet has been measured above the level of the Kansan gumbotil (fig. 47), and thicknesses somewhat greater have been reported by well drillers.

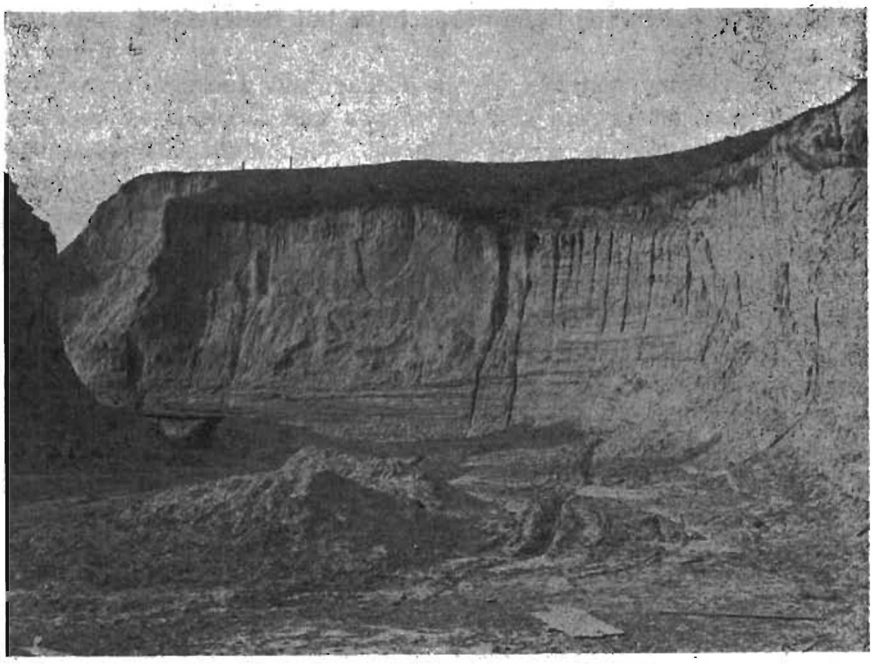


Figure 47. Cut showing 90 feet of Peorian loess, near Missouri Valley, Harrison County.

The characteristic features of the thick loess area are the apparent lack of system in the divides, the sharp hills with stepped slopes, and steep valley walls in many places cut by gullies. The relief is more than 200 feet within distances of a few miles. The area is very rough for a region of such moderate relief.

The interstream areas do not rise by successive elevations to the divides but present a series of irregular, broken, north and south ridges which face the west and are interrupted at each streamway. Figure 48 illustrates this north-south trend of the loess ridges just east of the Missouri River Valley. The prevailing westerly winds which carried the loess chiefly from the Missouri River flat have been the controlling factor in the distribution and development of the loess topography.

The hills which separate the waterways are in many places narrow-crested and steep-sided and have a series of small terraces or steps called "cat-steps" on the more abrupt slopes. These "cat-steps" are the result probably of slipping or faulting along the characteristic vertical joint planes of the loess.

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

Typical Sections of the Peorian Loess in Iowa

With the exception of the area of the Mankato lobe of the Wisconsin glacier, loess of Peorian age is in the upper part of nearly every Pleistocene section in the state. The sections which are given here are presented because they seem to be typical of the many hundreds of similar loess sections that are available over the state, or because they present some unusual feature of thickness, fossil content, or drift relationship. Every highway, every railroad, every stream and river valley of Iowa has exposed the compact, vertical-standing Peorian loess. Being exposed at the surface, easily cut in excavations and distinctive in color and texture, this deposit is of widespread interest.

Figure 48. Airplane view of north-south trending loess ridges on the Iowa side of the Missouri River Valley. (Photo by Des Moines Register-Tribune).

In Johnson County the North Liberty lobe of the Iowan drift extends from the northeast corner of the county to 1 mile southeast of North Liberty. Since the melting of the ice of Iowan age the Iowa River has developed its course across the North Liberty lobe from west to east and forms a broad sandy flood plain which blends gradually into the southern portion of the drift plain. This thin drift containing characteristic large Iowan boulders occupies a low plain bordered by loess hills underlain by Kansan drift. As this area is somewhat typical of the conditions at the margin of the Iowan drift in eastern Iowa a section was taken 1½ miles north of North Liberty in the SW¼NE¼ sec. 1, Penn Township, (T.80 N., R. 7 W.), Johnson County, in one of the hills bordering the margin of the Iowan drift plain (fig. 49). Here 52 feet in all, 18 feet exposed and 34 feet in a boring, were studied. Although the base of the loess was not reached in this section, another boring farther down the hill showed the loess to be on Kansan drift.

The loess is yellow and very irregular in mechanical composi-

Figure 49. Loess hill bordering the Iowan drift plain near North Liberty, Johnson County. A 52-foot loess section was obtained here.

tion. With the exception of the upper 5 feet, all is calcareous and contains many limy concretions which have been formed about the roots of plants.

The section is fossiliferous except for the 5 feet at the top. The section is as follows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, yellow, no fossils	5	
Loess, unleached, mostly fossiliferous, numerous limy concretions, very irregular in size grade, sandy layers. Known depth	47	

A detailed study of the fossil mollusks collected from the loess of this section has been made by Cameron.[102] This study indicates a damp, woodland environment during deposition of the basal loess, with a gradual change to a dryer climate and a more open type of vegetation during accumulation of the upper loess. The loess is thought to have been blown in relatively quickly, this rapid deposition being reflected in the scattered vertical repre-

[102]Cameron, Cornelia, Comparative study of the fossils of two loess sections in Iowa: Thesis, Dept. of Geology, State Univ. of Iowa, 1935.

sentation of the fossils, and by the notable irregularity of the size grades of the material, which is shown by the series of mechanical analyses made by P. T. Miller (fig. 50). This section is but a few hundred yards from the border of the North Liberty lobe of the Iowan drift (fig. 51).

Another section near the Iowan drift boundary in Johnson County is at the Goss brick yard in the northeastern part of Iowa City, (T. 79 N., R. 6 W.). Here the loess is known to have a thickness of more than 30 feet, but recently only about half of this thickness has been free from wash and slumping, and available for study. The section shows:

	Feet	Inches
Peorian intraglacial substage:		
Loess, leached, yellow with several undulating, horizontal, ferruginous bands. No fossils	5	
Loess, unleached, bluish gray, streaked with red due to oxidation of the vertical and horizontal root tubules, highly fossiliferous. Exposed	10	

This section is interpreted by Cameron as representing an area of slower loess accumulation and more even conditions of

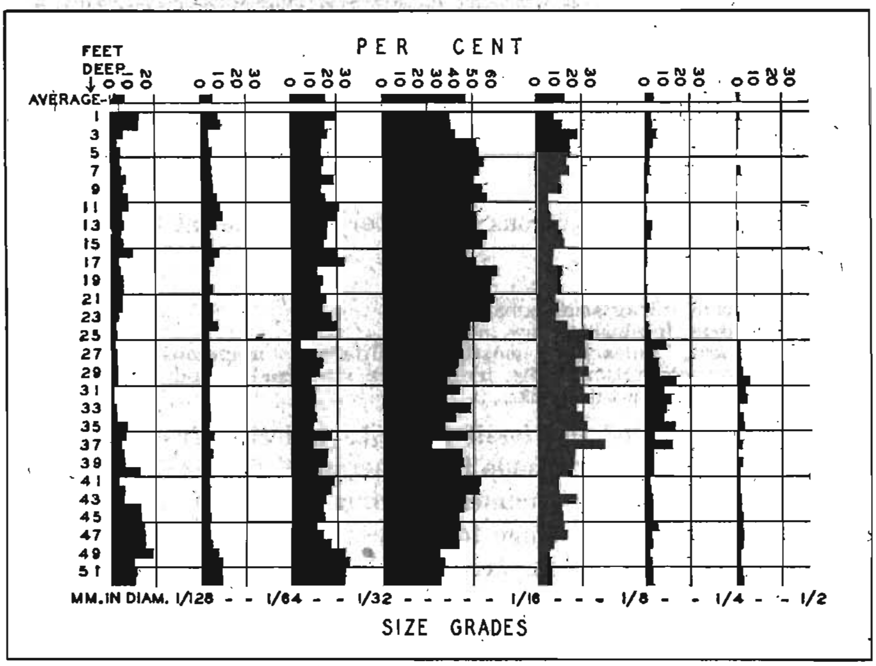


Figure 50. Graph showing a series of mechanical analyses of a loess section near North Liberty, Johnson County. Samples taken 2 feet apart vertically.

Figure 51. Topographic map of the North Liberty area showing the location of the 52-foot loess section.

climate and vegetation than the North Liberty section. The loess is more indicative of a continued damp, well-forested environment. In the Gaulocher pit which adjoins the Goss pit, contact of the yellow and gray phases of the loess is sharp, and the effect of oxidation of the plant roots is strikingly apparent (fig. 52).

A very unusual Peorian section occurs in the NE¼ sec. 15, Franklin Township, (T. 80 N., R. 22 W.), Polk County, in a cut through the top of a hill along the northeast valley wall of the Skunk River. This cut lies about 6 miles north of Mitchellville and is known as the Mitchellville cut. The hill is locally known as Lookout Mountain, the top of which stands 240 feet above the level of the river. A cut 38 feet deep was made in the recent construction of State highway 64 (formerly 88), and additional boring to a depth of 25 feet gave a vertical section of 63 feet. The section shows:

	Feet	Inches
Mankato glacial substage:		
Till, coating the top of the hill, contains a large amount of loess. The irregular contact between the till and the underlying loess was developed by glacial plowing. Average thickness of the till	5	
Peorian intraglacial substage:		
Loess, oxidized and leached	3	
Loess, oxidized and unleached	15	
Loess, unoxidized and unleached	40	

Figure 52. View in the Gaulocher clay pit, Iowa City, Johnson County, showing two phases of loess and effect of plant roots in oxidation and deoxidation.

Within the loess part of the section there is much woody material, with logs several feet in length showing little replacement or alteration, though some specimens show considerable disintegration. The unleached loess is highly fossiliferous and it is clear that the plant life and the animal life represented here were living at the same time and in the same environment. A detailed study of the fossil invertebrates from this cut was made by Cameron. The loess was found to be fossiliferous throughout. The snails are predominently of the woodland type, only one of 16 species of gastropods identified belonged to a water environment, this form being a fresh water pulmonate. A complete discussion of the invertebrate fauna of this section is given on page 194.

The vegetal material from this section requires further paleobotanical study, but a log at Iowa City collected from this section has been identified as yew, and spruce and hemlock have been identified by Cameron. Indications point to a coniferous forest living in a climate not immoderately cold, supporting a woodland snail fauna on its floor.

Just west of Panora, Guthrie County, in the middle of the north line of sec. 6, Cass Township, (T. 80 N., R. 30 W.), is another fine cut showing Peorian loess overlain by Mankato drift. It is on the west slope of the Raccoon River. The section is as follows:

	Feet	Inches
Mankato glacial substage:		
Till	3	
Peorian intraglacial substage:		
Loess, unleached	8	
Kansan glacial stage:		
Till, strongly oxidized, leached	5	6
Bedrock:		
Reworked shale. Exposed	7	6

These relationships are photographically shown in figure 53.

A section showing a humus accumulation on the Peorian is found along the east-west road just west of the adjoining corners of secs. 8, 9, 16 and 17, Lincoln Township, (T. 79 N., R. 4 E.), Scott County. Here the section is:

	Feet	Inches
Peorian intraglacial substage:		
Humus		6
Loam		6
Loess, leached, compact, yellow to light brown in color	4	10
Loess, unleached, has concretions. Exposed	1	

This section is on the Illinoian upland and is characteristic of the normal amount of leaching which has occurred in this area when no erosion has taken place.

Leached Peorian loess has been used in the manufacture of clay and pottery products. A good section of leached Peorian loess is shown in the Keota Brick and Tile Co. pit, in the southeastern part of Keota, Keokuk County, in the NE¼ sec. 25, Lafayette Township, (T. 76 N., R. 10 W.).

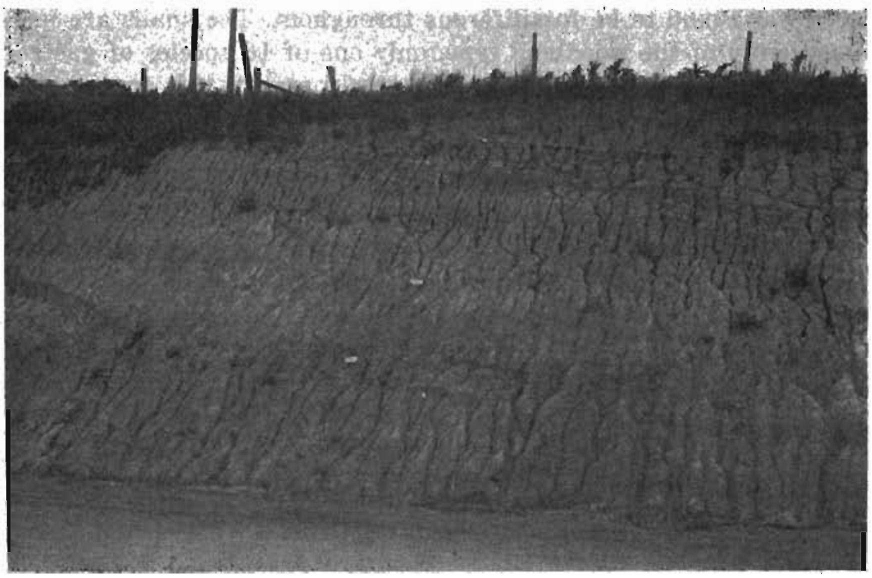


Figure 53. Peorian loess overlain by Mankato drift, just west of Panora, Guthrie County.

	Feet	Inches
Peorian intraglacial substage:		
Soil zone, dark to almost black, somewhat mealy clay	2	
Loess, leached, gray to faint yellowish clay with numerous root fibers; when dry breaks into irregularly shaped masses, when wet cuts with a smooth surface. Upper part seen as polygonal columns............	6	

One hundred feet farther north in the pit is a section showing only 5 feet of leached loess, below which is a distinctly gray unleached loess filled with concretions and shells, exposed for 3 feet. The pit is at the upland level.

Great thicknesses of Peorian loess are exposed in many of the bluffs and road cuts through the hills bordering Missouri River Valley along the western boundary of the state. Just southeast of Council Bluffs, in Pottawattamie County, the loess can be seen in high bluffs, the thickness ranging up to 100 feet.

Characteristics of the Peorian Loess

General Characteristics

Peorian loess is light-yellow and gray in color and shows essentially no stratification. Its particles are angular and are evidently the result of rock abrasion, grinding and impact. Their diameters range from 1/2 millimeter to 1/256 millimeter, but the greatest percentage falls in the size grade 1/8 millimeter to 1/64 millimeter. Quartz is by far the most common mineral. Other constituents are feldspar, muscovite, glauconite, pyrite, magnetite, ilmenite, hornblende, pargasite, glaucophane, actinolite, tremolite, hypersthene, enstatite, augite, aegerite-augite, aegerite, chlorite, andalusite, epidote, zircon, garnet, tourmaline, titanite, biotite, staurolite, topaz, kyanite, rutile, brookite, barite, monazite, riebeckite, basaltic hornblende, and anthophyllite.

Chemically, the Peorian loess of Iowa contains SiO_2, TiO_2, MgO, CaO, Na_2O, K_2O, Al_2O_3, Fe_2O_3, FeO, MnO, P_2O_5, H_2O, CO_2, ZrO_2, S, Cr_2O_3, and BaO. Where the loess has been exposed to chemical weathering over a sufficient time, the calcium carbonate has been leached out.

Curiously shaped calcareous concretions known as loess kindchens and pipestems, deposits of calcium carbonate about plant roots, are found in many places in the loess. The fossils with few exceptions are of land origin and in large part consist of land gastropods.

A characteristic feature of the loess is its ability to stand in vertical cliffs (fig. 54). Striking examples of this feature may be seen along Missouri River where the loess ranges in thickness up to 100 feet. It has been suggested that this is due to the angularity of the composing particles, and to buttressing by rods and tubes which have been formed about the plant roots and stems. The loess was laid down over and about them and calcium carbonate was later deposited. The loess is distributed generally but not uniformly over the uplands where it forms a more or less irregular veneer and is thickest at the tops of the more prominent ridges. In fact, the greater prominence of these ridges is due in large part to the accumulated loess. It is significant that the deposit is absent from alluvial flats and frequently from the bases of bluffs.

In thickness, the loess ranges from zero to about 100 feet, but if it were spread evenly over the entire surface of the state it would form a deposit about 10 feet thick.

Mechanical Analyses

Series of Peorian loess samples collected from various parts of the state have been analyzed in the laboratory by P. T. Miller. The samples were collected along field traverses so that the relationship of size of particles to distance from the probable source

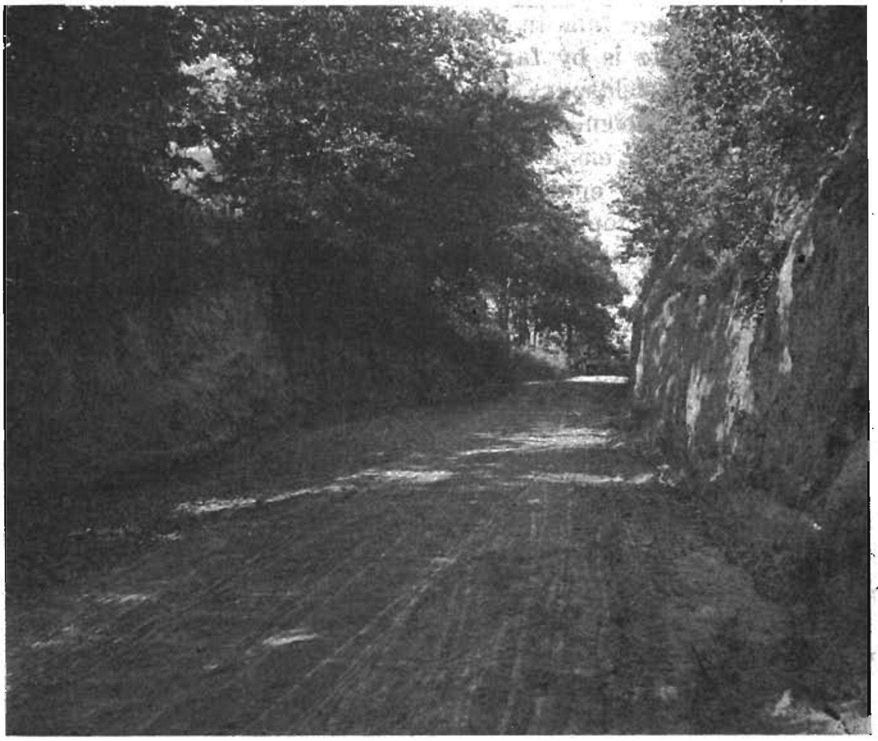


Figure 54. Vertical walls in a Peorian loess cut near Magnolia, Harrison County.

might be ascertained. The traverses along which the samples were collected are shown on the map of Iowa in figure 55.

In northwestern Iowa two series of samples were collected. One was between Sioux City and the Wisconsin drift border near Sac City and the other was between Sioux City and Spencer. The analyses of samples between Sioux City and Spencer (fig. 56), show no change in texture from west to east. The section between Sioux City and Sac City (fig. 57), shows that the loess becomes slightly finer toward the east.

In southern Iowa samples were collected between Donnellson and Sidney. They show that the loess is of about equal texture from Lee County west to Decatur County. From Decatur County to Taylor County the thin loess is slightly finer. From Taylor County to the Missouri River the loess becomes slightly coarser in texture (fig. 58).

In the section between Tama and Iowa Falls (fig. 59), all on

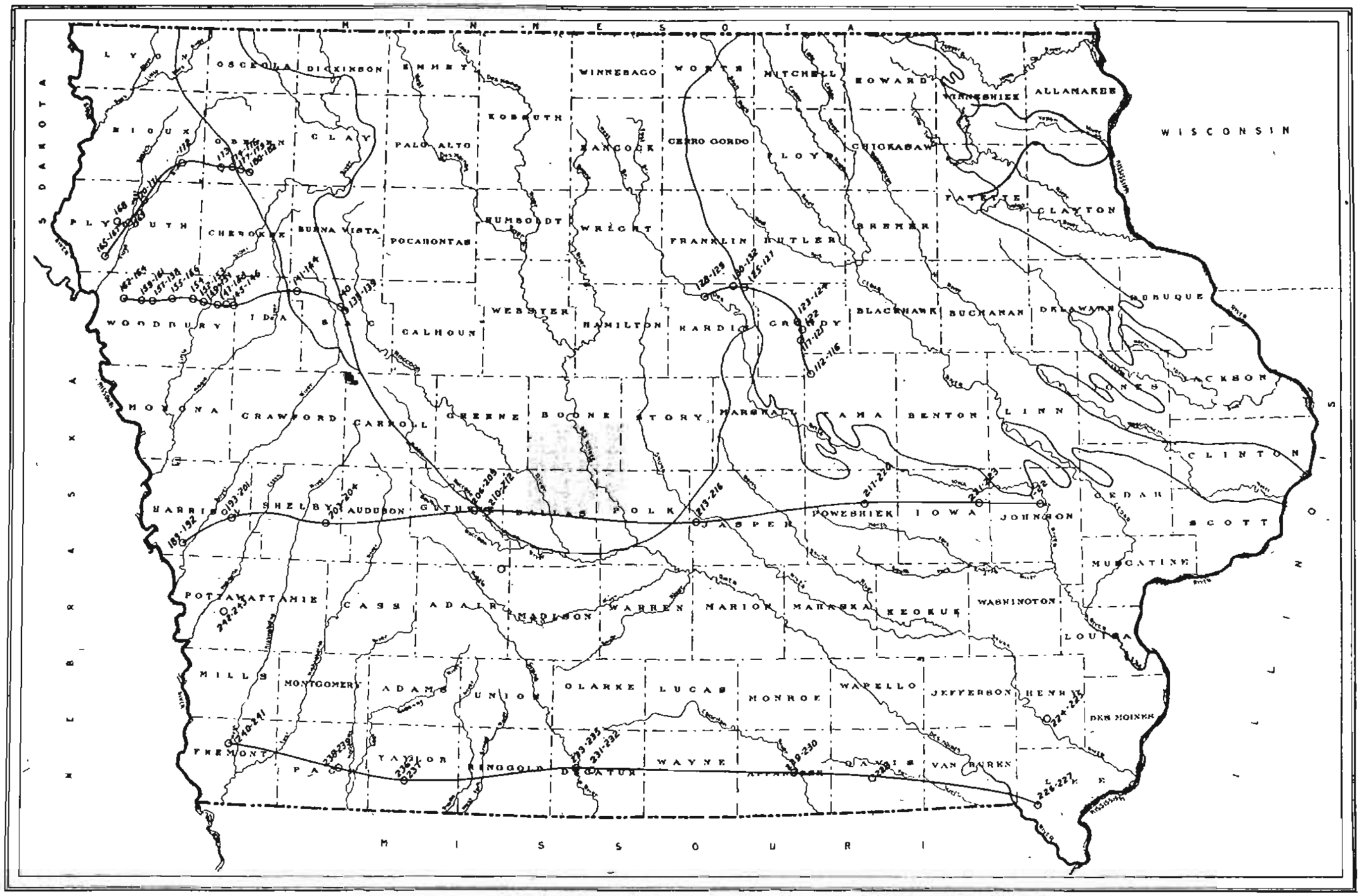


Figure 55. Map of Iowa showing traverses followed in collecting Peorian loess samples used in laboratory analyses.

the Iowan drift surface, the texture of the loess varies within cuts and local areas. There is no general variation between these two places. The section across Iowa from Missouri Valley to Iowa City (fig. 60), shows the loess becoming slightly finer from the Missouri River east across Shelby and Guthrie Counties. However, farther east in Poweshiek and Iowa Counties it is coarser and at Iowa City it is finer, about the same as in Guthrie County.

Samples of Peorian loess between the Iowan drift border in northeastern Iowa and the Mississippi River were collected for laboratory analysis. Samples were collected at a depth of 4 feet as well as at a depth of 7 feet. One set of samples was collected along a traverse from Ridgeway in Winneshiek County to McGregor, along the Mississippi River, in Clayton County. Eighteen samples were collected at a depth of 4 feet, and 11 samples were collected at a depth of 7 feet.

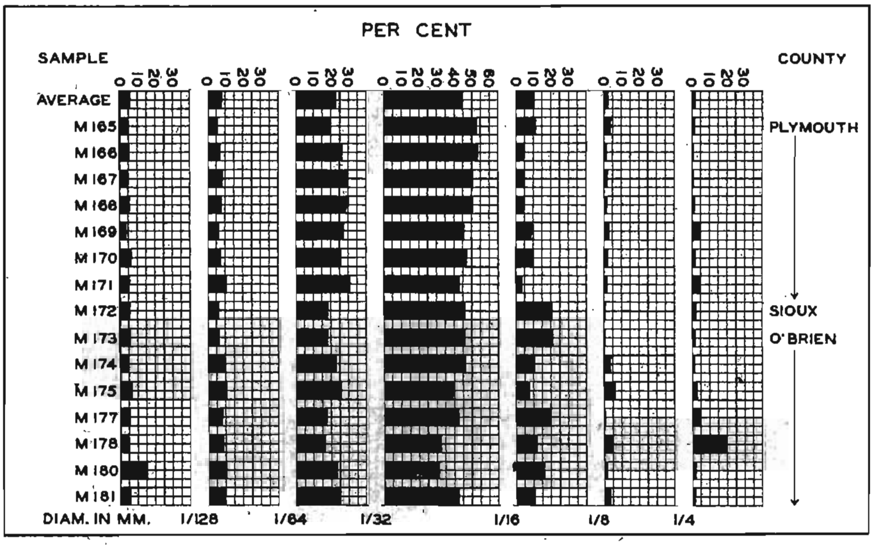


Figure 56. Graph showing the series of mechanical analyses of loess samples collected between Sioux City and Spencer.

The second traverse was made from West Union in Fayette County to McGregor in Clayton County. Twenty-two samples from the 4-foot depth were collected and 17 samples from the 7-foot depth. The averages of these suites of samples are given in figures 61 and 62. Figure 63 shows the average mechanical analysis percentages for loess samples collected throughout the state.

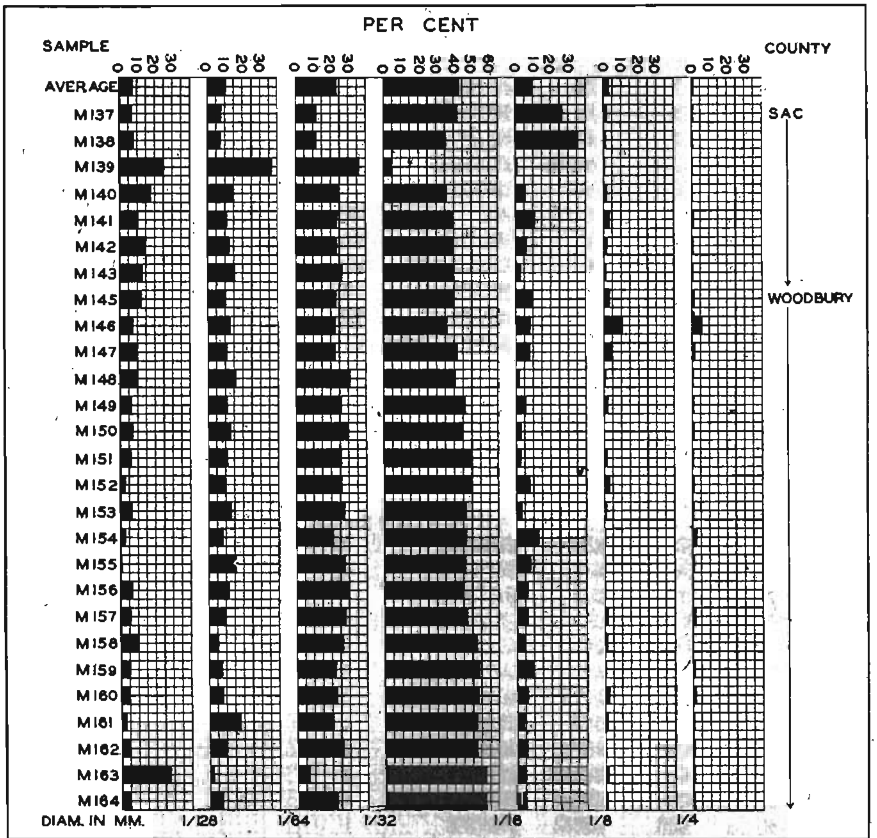


Figure 57. Graph showing the series of mechanical analyses of loess samples collected between Sioux City and Sac City.

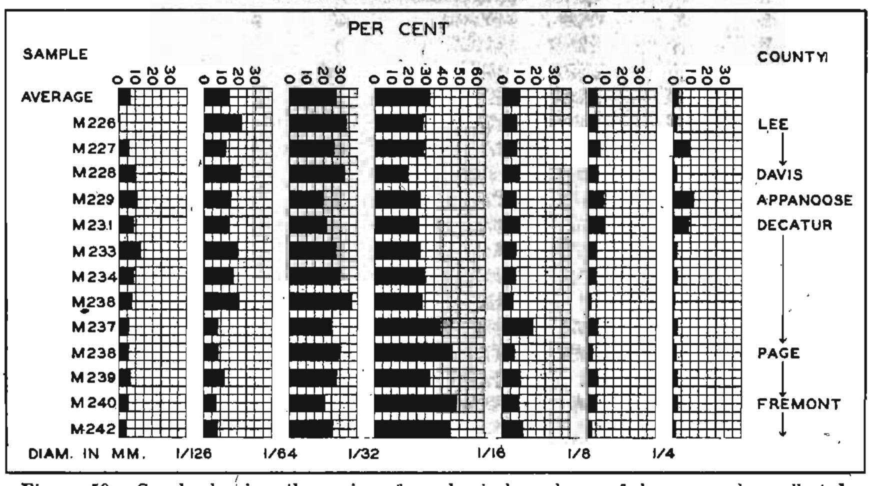


Figure 58. Graph showing the series of mechanical analyses of loess samples collected between Donnellson and Sidney.

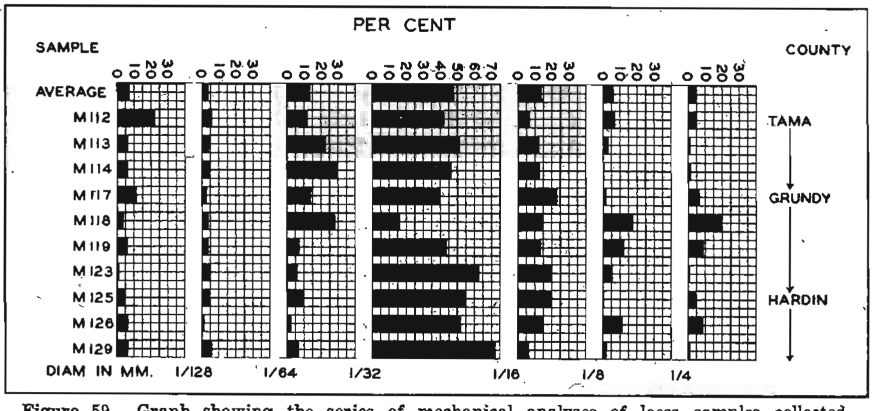


Figure 59. Graph showing the series of mechanical analyses of loess samples collected between Tama and Iowa Falls.

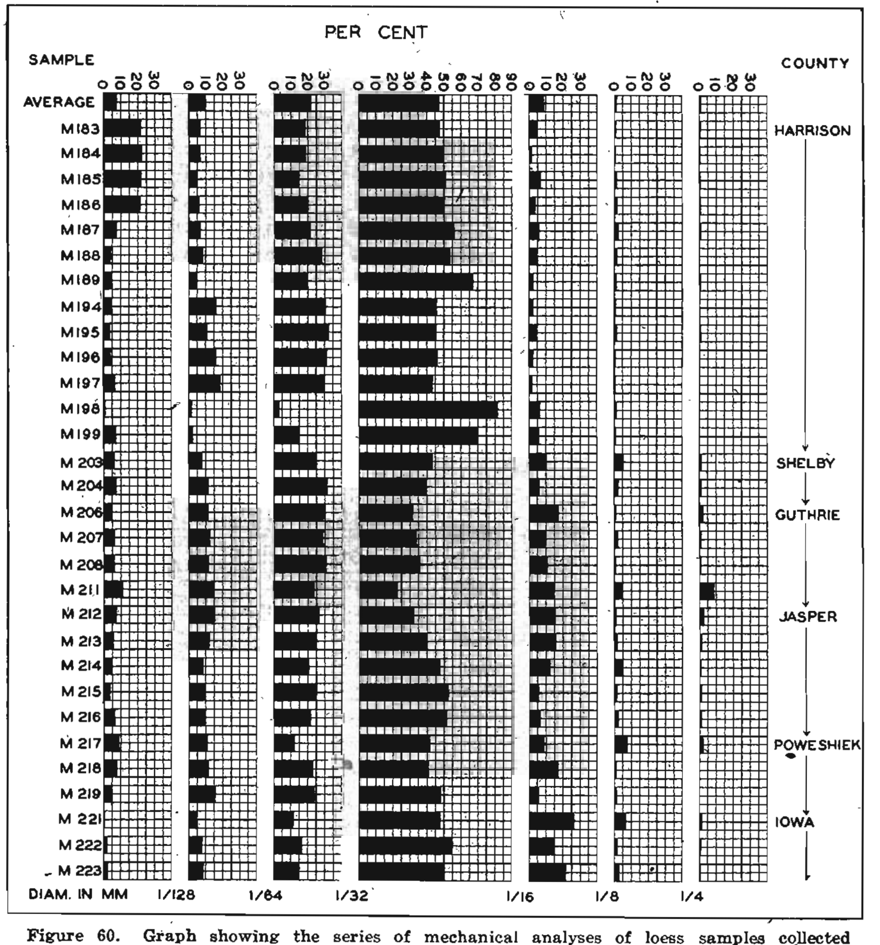
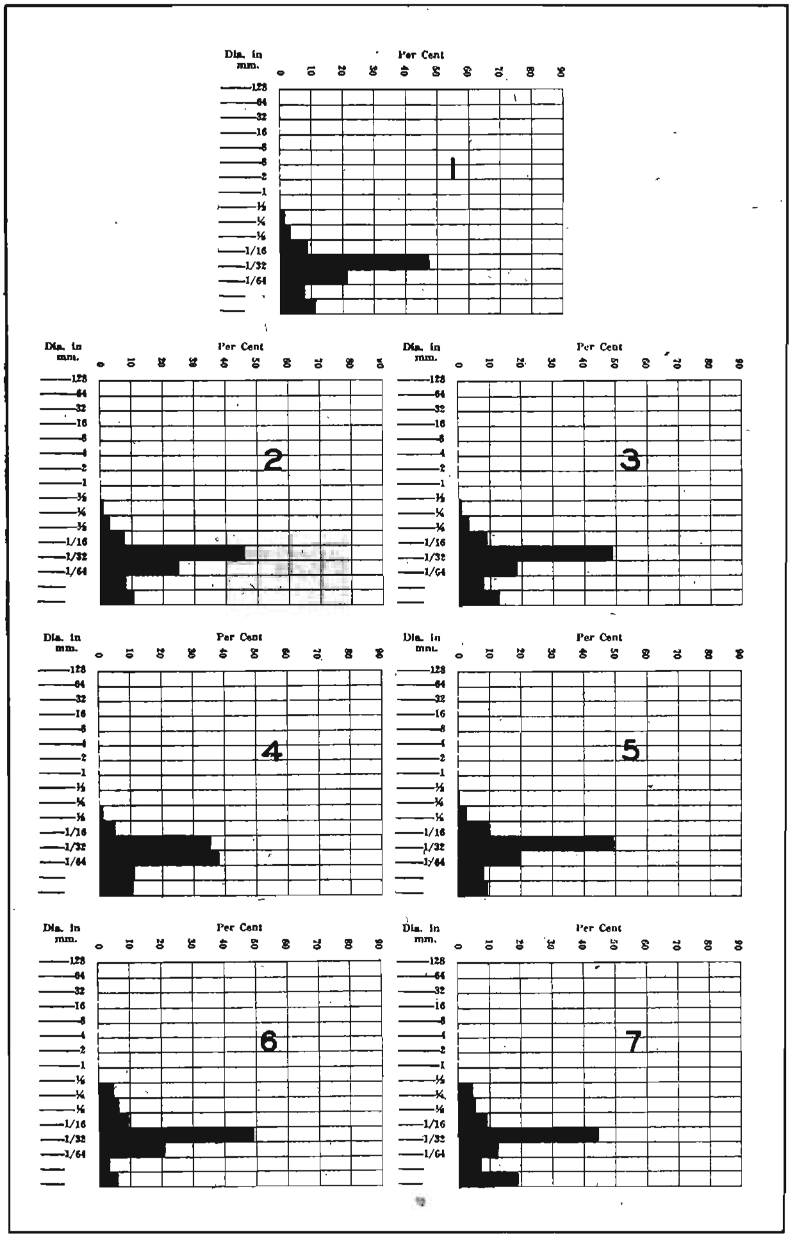
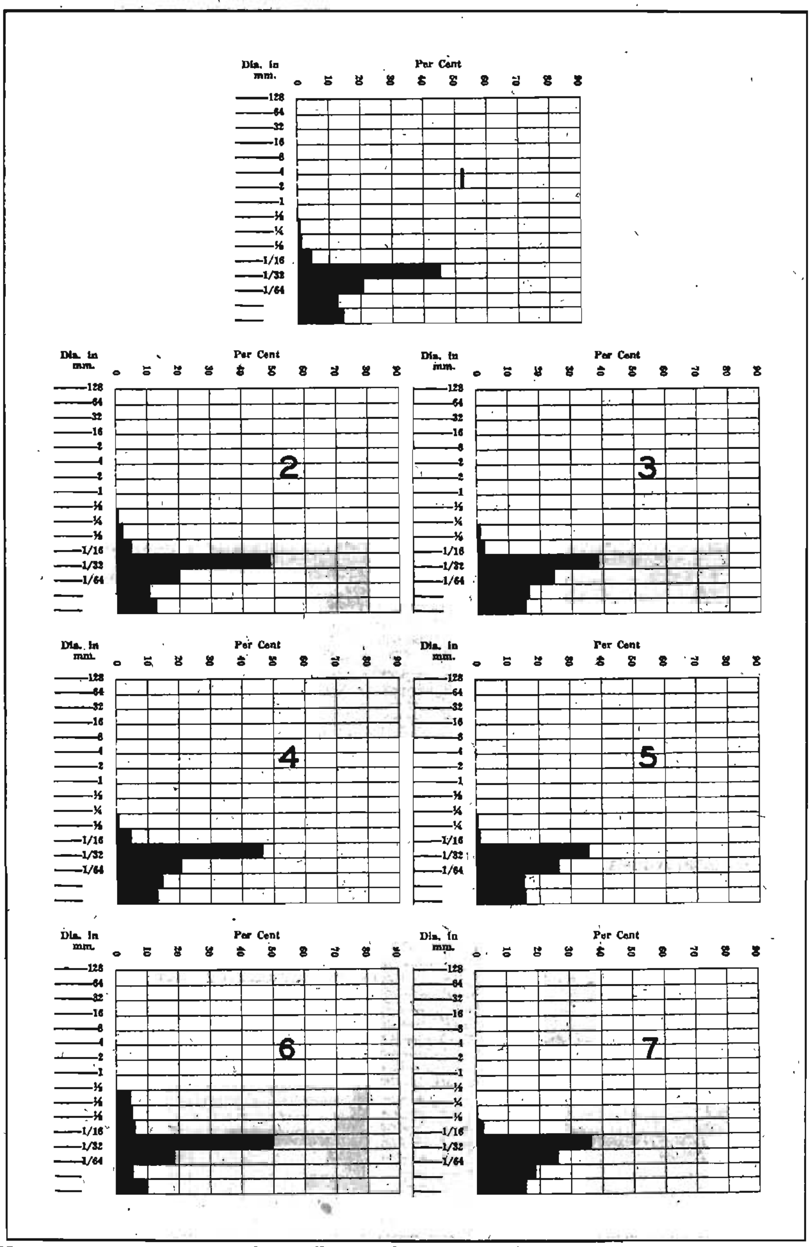


Figure 60. Graph showing the series of mechanical analyses of loess samples collected between Missouri Valley and Iowa City.



No. 1. Average of 40 samples of Peorian loess taken from 4 feet deep, between the Iowan drift border and the Mississippi River.
No. 2. Average of 22 samples taken from 4 feet deep between McGregor and West Union.
No. 3. Average of 18 samples taken from 4 feet deep between McGregor and Ridgeway.
No. 4. Average of 4 samples taken from 4 feet deep southwest of McGregor.
No. 5. Average of 4 samples taken from 4 feet deep northwest of McGregor.
No. 6. Average of 4 samples taken from 4 feet deep near Iowan drift border near West Union.
No. 7. Average of 4 samples taken from 4 feet deep near Iowan drift border near Ridgeway.
Figure 61. Graphs showing mechanical analyses of Peorian loess collected in northeastern Iowa.



No. 1. Average of 40 samples of Peorian loess taken from 7 feet deep, between the Iowan drift border and the Mississippi River.
No. 2. Average of 22 samples taken from 7 feet deep between McGregor and West Union.
No. 3. Average of 18 samples taken from 7 feet deep between McGregor and Ridgeway.
No. 4. Average of 4 samples taken from 7 feet deep southwest of McGregor.
No. 5. Average of 4 samples taken from 7 feet deep northwest of McGregor.
No. 6. Average of 4 samples taken from 7 feet deep near Iowan drift border near West Union.
No. 7. Average of 4 samples taken from 7 feet deep near Iowan drift border near Ridgeway.
Figure 62. Graphs showing mechanical analyses of Peorian loess collected in northeastern Iowa.

A number of conclusions may be drawn from the study of the mechanical analyses of Peorian loess. There are distinct variations in the loess within single cuts and local areas. These are more distinct in the analyses than the general variations from one part of the state to another.

As shown in the reference to each section studied, there are slight general changes from place to place.

The Missouri River loess becomes finer with increase in distance east of the Missouri River. Likewise, the loess becomes finer in northeastern Iowa with increasing distance from the Iowan drift border. In certain areas within the state such as Marshall, Poweshiek, and Iowa Counties the loess is as coarse as in any part of the state. Farther south in Davis, Appanoose and surrounding counties the texture is as fine as in any part of the state.

The most logical reason for this difference in texture is the source of material and direction of transportation. Much of the loess along the Missouri River comes, no doubt, from the Missouri River flats and was transported eastward. This would give a general thinning toward the east as well as a decrease in the coarser material.

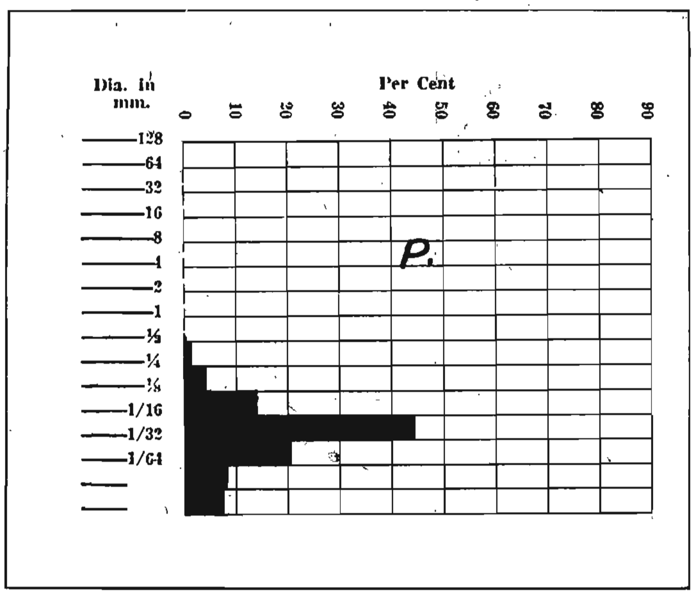


Figure 63. Graph showing the average mechanical analysis for Peorian loess samples collected throughout Iowa.

Central Iowa received a considerable supply from the valleys carrying drainage from the Iowan drift and consequently would be of coarser texture. In south-central Iowa, the supply of water and also the supply of loess would be less, as few of the streams head up within the Iowan drift. Also, with increase in distance from the Iowan drift the stream load would be increasingly finer.

In northeastern Iowa the series of samples collected between McGregor and the Iowan drift border just west of West Union and between McGregor and the Iowan drift border east of Ridgeway show two things: (1) A variation in texture between samples collected only a short distance apart, and (2) the average texture

Heavy fraction	Peorian loess except North Liberty and West Union cuts	Peorian loess of North Liberty cut	Peorian loess of West Union cut	Iowan till except West Union cut	Iowan till of West Union cut	Kansan till	Mankato till	Aftonian loess (?)	Loveland loess	Peorian loess of all Iowa	Iowan till of all Iowa
Pyrite	7.92	1.33	2.01	6.60	1.65	2.55	2.00	1.04	16.40	4.05	3.30
Magnetite and Ilmenite	19.20	13.78	19.15	10.58	20.20	11.12	4.50	10.00	9.03	17.69	16.99
Hornblende	27.32	36.29	29.37	43.30	32.03	38.14	44.00	43.80	32.36	30.76	35.69
Pargasite	.62	1.24	1.98	1.10	1.76	1.09	.90	1.04	1.75	1.02	1.51
Glaucophane	.32	1.48	1.81	.55	1.85	.42	.45	1.04	1.31	1.06	1.48
Actinolite	.50	1.73	.73	1.07	.61	.78	.50	2.06	1.02	1.29	.76
Tremolite	.11	.75	.55	......	......	1.09	......	1.00	......	.52	......
Hypersthene	1.13	1.46	2.73	2.75	1.66	1.81	2.50	1.08	.72	1.34	2.02
Enstatite	.57	1.52	.63	1.08	.24	1.33	.50	3.15	.43	1.18	.52
Augite	2.29	12.02	25.09	5.30	1.92	3.45	13.20	3.10	2.40	6.95	3.05
Aegerite-Augite	.11	.02	.23	......	.36	.54	......	......	......	.09	.24
Aegerite	.27	.35	.36	.07	.16	.54	.10	.38	1.06	.32	.13
Chlorite	3.56	1.21	.12	.80	.18	1.57	1.00	......	.42	2.05	.39
Andalusite	.34	1.35	.92	.34	.95	......	1.00	2.08	.80	.99	.75
Epidote	6.35	10.35	5.02	10.55	3.30	7.51	12.00	6.00	8.76	8.08	5.72
Zircon	4.35	3.13	7.26	3.27	9.26	5.55	3.50	4.20	9.22	4.38	7.26
Garnet	5.80	5.51	8.07	7.48	10.18	15.22	10.01	9.38	5.47	6.30	9.26
Tourmaline	.49	1.81	2.89	.88	1.72	.49	.53	......	3.23	1.51	1.44
Titanite	.99	.82	1.90	.29	1.71	.78	1.01	1.04	2.23	.89	1.24
Biotite	15.71	.76	2.36	.63	2.14	3.77	......	2.06	.49	6.66	1.64
Staurolite	.30	.95	.54	.69	1.09	......	.47	4.18	.80	.70	.96
Topaz	.44	.21	2.96	.19	1.77	.18	......	1.00	.27	.29	1.24
Cyanite	.30	.34	......	.75	......	.73	......	1.08	.27	.33	.08
Rutile	......	.38	1.35	.71	.37	.73	.98	......	.27	.25	.48
Brookite	......	......	.12	.10	.13	......	......	.20	.12	......	.12
Barite	.11	.99	......	.13	......	.01	.51	......	......	.68	.05
Miscellaneous	.18	.08	......	.92	1.21	......	......	......	.26	.12	1.11
Monazite	.16	.08	.32	.27	.39	.12	......	......	......	.11	.35
Riebeckite	.08	.07	.10	.15	.52	......	.15	1.08	.10	.07	.40
Basaltic Hornblende	.46	.07	.60	.28	1.71	.54	......	1.04	.54	.21	1.23
Spinel	......	......	.68	......	.36	......	.12	......	......	......	.24
Anthophyllite	.08	......	.28	.02	.54	.95	......	......	.27	.03	.37
Hedenbergite	......	......	.17	......	.24	......	......	......	......	......	......
Light Fraction											
Quartz	75.56	77.79	69.85	76.80	76.10	87.20	74.50	74.00	81.30	77.15	76.33
Undiff. Feldspar	21.92	19.72	27.95	20.28	21.77	9.29	21.30	23.45	9.82	20.36	21.27
Microcline	.95	1.29	1.06	1.20	.85	1.74	1.53	.84	7.58	1.17	.97
Plagioclase (Albite)	1.14	1.00	1.09	1.79	1.21	1.94	2.53	1.68	3.32	1.05	1.40
Muscovite	.47	.27	......	.12	......	......	.20	......	......	.34	.04
Glauconite	......	.01	......	......	.06	......	......	......	......	.01	.04

Figure 64. Mineralogical analyses of various Pleistocene materials of Iowa.

of the material becomes finer with increased distance from the Iowan drift border. The loess east of Ridgeway is all typical loess but some sections near the Iowan drift border west of West Union are composed of dominantly fine sand.

Mineral Analyses

Petrographic studies have been made by P. T. Miller of a large series of samples of Loveland loess, Peorian loess, Iowan till, Kansan till, and other materials for the purpose of comparison. The minerals of specific gravity greater than 2.89 were separated from those lighter by using a heavy liquid (bromoform) in a centrifuge. Each mineral separate was studied under both binocular and petrographic microscopes. The minerals of each of these separates were mounted for study in liquids of different indices of refraction. The mineralogic percentages of both the heavy and light fractions of the several Pleistocene materials are shown in figure 64.

The striking correlation between heavy minerals of Loveland loess, Peorian loess of all Iowa, Iowan till of all Iowa, and Kansan till is readily seen (fig. 65). The Iowan till of the West Union cut and the Iowan till of all Iowa closely resemble each other as do the Kansan till and the Iowan till of all Iowa. That the Peorian

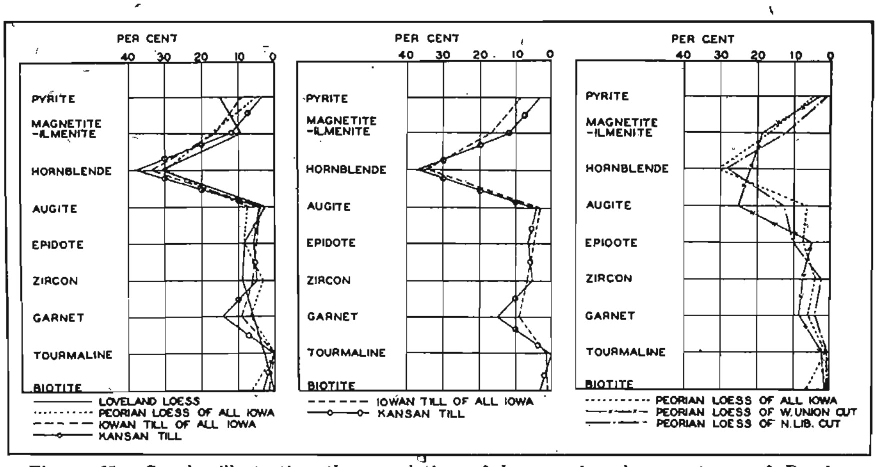


Figure 65. Graphs illustrating the correlation of heavy mineral percentages of Peorian loess, Iowan till, Loveland loess and Kansan till, of Iowa.

has slight local differences from place to place is brought out in the chart that compares the loess of the West Union cut and the North Liberty cut with the Peorian loess of all Iowa.

From these results it seems fair to assume that the tills furnished the ultimate source of the loess derived directly from the flood plains of the Missouri River. The Peorian deposits of eastern Iowa came presumably largely from the Iowan drift and outwash.

Chemical Analyses

Samples of Peorian loess chosen from two localities where the loess has been studied in great detail with respect to physical, mineralogical and fossil relationships, were submitted to Dr. L. C. Thomas for complete chemical analysis. The analyses of the chemical components of the two loess samples are given in the following charts:

Peorian loess, from the NW¼NE¼ sec. 1, Penn Township, (T. 80 N. R. 7 W.), Johnson County. Sample taken 5 feet below the surface. Leached.

SiO_2	75.17%	
TiO_2	0.68	
Al_2O_3	10.21	
Fe_2O_3	2.24	
FeO	0.43	
MnO	0.06	
MgO	1.03	
CaO	1.78	
Na_2O	0.89	
K_2O	1.87	
P_2O_5	0.29	
H_2O+	2.31	(ignition above 110C.)
H_2O-	1.91	(ignition below 110C.)
CO_2	0.62	
ZrO_2	0.15	
Cl	0.06	
SO_3	0.40	
S	0.52	
$(Ce, Y)_2 O_3$	0.17	
Cr_2O_3	0.00	
BaO	0.03	
Total	100.72%	

A loess analysis was made of a sample from a second section in Fayette County:

Peorian loess, from near the middle of the north line of the NE¼ sec. 16, Windsor Township. (T 94 N., R 9 W.), 6 inches above the contact with the underlying till. Unleached.

SiO_2	63.92%
TiO_2	0.77
Al_2O_3	8.05
Fe_2O_3	1.38
FeO	0.27
MnO	0.06
MgO	3.85
CaO	8.27

Na_2O	1.40	
K_2O	0.99	
P_2O_5	0.35	
H_2O+	1.61	(ignition above 110C.)
H_2O-	1.26	(ignition below 110C.)
CO_2	7.15	
ZrO_2	0.10	
S	0.80	(total S as S)
Cr_2O_3	0.00	
BaO	0.02	
Total	100.15%	

A tabulation of 45 samples of published analyses of loess and loess-like material, along with the bibliographic source of each sample, has been prepared by Dr. Thomas. This tabulation is given in chart 1 of the appendix. A comparison of the two Iowa analyses with the analyses listed in chart 1 clearly shows that the loess of these two sections in Iowa is very similar in composition to many of the samples reported in the literature, whether they were taken from the Upper Mississippi River Basin or from China or the Rhine Valley.

Several other analyses of leached Peorian loess were made by Dr. J. N. Pearce in order to compare the SiO_2, Fe_2O_3, Al_2O_3, CaO, and MgO content. The localities from which the loess was taken are as follows:

A. From cut on Chicago, Milwaukee, St. Paul and Pacific Railroad, 1 mile west of Murray, (T. 72 N., R. 27 W.), Clarke County.
B. From cut west of the Chicago Great Western Railway crossing, Union County.
C. From cut on the Chicago, Milwaukee, St. Paul and Pacific Railroad about 1 mile east of Foster. (T. 71 N., R. 16 W.), in the southeast corner of Monroe County.
D. From cut west of Agency, (T. 72 N., R. 13 W.), Wapello County.
E. From bluff north of Fort Madison, (T. 68 N., R. 4 W.), Lee County.
F. From cut northwest of North Liberty, (T. 80 N., R. 7 W.), Johnson County.
G. From cut on Chicago Rock Island and Pacific Railway near the north boundary of sec. 3, Lincoln Township, (T. 72 N., R. 21 W.), Lucas County.

Figure 66 shows the chemical analyses made by Pearce in graph form of leached Peorian loess from these seven sections.

The seven analyses show close similarities, the greatest variation being in the SiO_2 content. A comparison of these analyses of leached loess with the unleached loess of the West Union section, sec. 16, Windsor Township, (T. 94 N., R. 9 W.), Fayette County, shows a marked increase in CaO and MgO in the unleached loess.

Two specimens of Peorian loess from Marshall and Cass Counties respectively have been analyzed in detail mechanically and chemically by Cuthbert[103] and the analyses given show percentages similar to the above graphs.

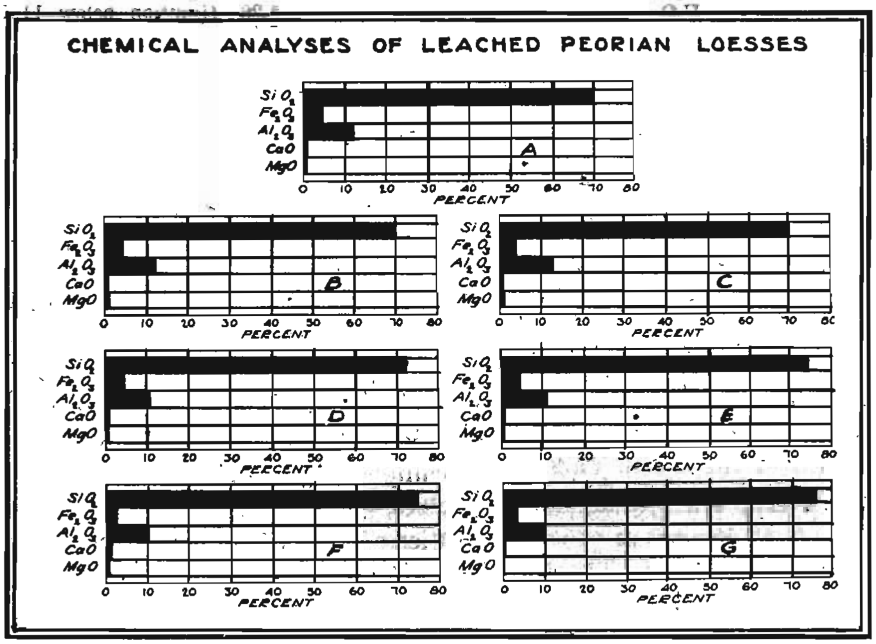


Figure 66. Graph showing the chemical analyses of leached Peorian loess.

Fossils of the Peorian Loess

Vertebrates

There is a striking paucity of vertebrate fossils reported from the Peorian loess of Iowa. Just why this scarcity should be, when other indications point to a great abundance of mammals inhabiting the area has not been clearly understood. The most plausible argument is that the conditions for burial and preservation of skeletal parts by the wind-blown silt and clay were unfavorable, and that in most cases complete decay of the bones and teeth occurred before burial.

There is little doubt but that a rich vertebrate fauna existed in Iowa and surrounding areas throughout Wisconsin time. The abundance of both forest and plains mammals preceding the Wisconsin epoch, and the rich cave and flood-plain faunas associated with early man in America would seem to span the interval under

[103]Cuthbert, F. L., Petrography of two Iowa loess materials: Am. Mineralogist, vol. 25, pp. 519-527, 1940.

consideration. Deposits which may include the entire range of the Wisconsin epoch, such as Conard's Fissure in Arkansas, indicate no impoverished zone which might be correlated with a Peorian scarcity of life.

The loess as a preserving medium for organic remains is chemically and physically well suited for the purpose. A good terrestrial matrix for vertebrates should be fine enough so that damage to the organic remains does not occur in deposition; there should be sufficient porosity and permeability to permit solution and mineralization of the bones; and the matrix should contain sufficient mineral content to afford the mineral replacement occurring in normal fossilization. While the organic remains which have been found in the Peorian loess are not highly silicified, the essential qualities of a good preserving material are met.

Therefore, the lack of fossils must be due to conditions of burial, and there are several lines of evidence to substantiate this view. Except in a few localities, the accumulation of Peorian loess must have been exceedingly slow. Considerably more than half of the state has a covering of somewhat less than 10 feet of loess. It may be that the lack of numerous vertebrate fossils in the loess in Iowa is due largely to insufficiency of cover before the normal decay and disintegration of organic remains on the prairie or forest floor was complete. The absence of any well-defined soil zones in the Peorian loess of Iowa,[104] and the uninterrupted climatic sequences of the invertebrate fauna in the loess suggest that accumulation was fairly uniform. While the evidence in Iowa indicates that the loess was deposited very early in the Peorian interval, perhaps its rate of deposition was so slow that only the most minute of the readily perishable organic remains were covered and preserved.

A few vertebrate-bearing deposits of the loess are known. In most instances known to the authors, these localities show unusual thicknesses of the loess, those in Nebraska ranging up to 200 feet. McGee[105] reported the discovery of part of a skull of the extinct musk ox *Symbos cavifrons* in Peorian loess near Council Bluffs, Pottawattamie County. Shimek, whose study of the Peorian snail fauna led him to conclude that the loess was an inter-

[104]Several thin soil zones in the upper part of the Peorian loess in western Nebraska have been identified by Nebraska geologists. These fossil soils and the related soil zones in the Sand Hills formation are being studied by Drs. Lugn and Schultz, Department of Geology, University of Nebraska. Personal communication.

[105]McGee, W J, *Ovidos Cavifrons* from the loess of Iowa: Am. Jour. Sci., vol. 34, p. 217, 1887.

glacial deposit, suggested that this arctic type of mammal may have come from the Loveland rather than the Peorian. However, McGee describes the fossil as occurring at a depth of 12 feet in the loess, and at a height of 130 feet above the river level, an elevation higher than known Loveland occurrences, but well within the Peorian range which in this area may attain a depth of one hundred feet.

Udden[106] reported that the horn cores of a bison, probably *Bison occidentalis,* had been found in the loess also in Pottawattamie County, in a well at a depth of 14 feet.

There is some doubt about a discovery reported by Todd,[107] of tusks, teeth, jaws, a humerus, and other bones of a young elephant found between Glenwood and Pacific Junction, Mills County. The remains may have come either from the basal part of the thick Peorian loess or from the top of the underlying drift.

Also from Mills County, Udden[108] reported the finding of bones of a mammoth in the lower part of the loess at Malvern in a grading for the Chicago, Burlington and Quincy Railroad.

Perhaps one other Iowa section bears out the probable relation between depth and preservation of organic remains. In the Mitchellville cut, described on pages 169 to 171 of this report, well preserved logs and branches are conspicuous, an unusual occurrence in the Peorian loess. Accentuating this feature is the abnormal thickness of this section, which has a known depth of at least 58 feet though overridden by the Mankato glacier. The wood from this deposit is well preserved, and indicates fairly rapid burial.

In Nebraska, a very rich mammalian horizon known as the "*Citellus Zone*" occurs in the transition zone between the Loveland and Peorian loess phases. The zone includes the deep soil zone which has developed on the Loveland loess, and the basal 4 feet of Peorian loess. This zone has yielded many vertebrate specimens, and the great thickness of the Peorian, here perhaps the thickest definite Peorian loess in America, strongly favors the relation of the fossil remains to a quick burial of the mammals living on the old Loveland soil surface, by the great dust storms of early Peorian time. This zone, because of its recognizable

[106]Udden, J. A., Geology of Pottawattamie County: Iowa Geol. Survey, vol. 11, p. 260, 1901.
[107]Todd, J. E., Notes on the Geology of northwestern Iowa: Iowa Acad. Sci., Proc., p. 14, 1875-1880.
[108]Udden, J. A., Geology of Mills and Freemont Counties: Iowa Geol. Survey, vol. 13, p. 170, 1903.

character and fossil significance, has become an important datum in western Pleistocene stratigraphy.[109]

Invertebrates

The invertebrate fauna of the Peorian loess in Iowa has been recently studied in detail by Cameron. The following list of mollusks in the Peorian loess has been taken from the report of that investigation.[110]

Gastropoda

Terrestrial Pulmonata

Anguispira alternata (Say)
Carychium exiguum (Say)
Carychium exile H. C. Lea.
Circinaria concava (Say)
Cochlicopa lubrica (Muell.)
Columella edentulum alticola (Ing.)
Euconulus fulvus (Drap.)
Gastrocopta armifera (Say)
Gastrocopta contracta (Say)
Gastrocopta corticaria (Say)
Gastrocopta curvidnes (Gld.)
Gastrocopta holzingeri (Sterki)
Gastrocopta pentodon (Say)
Gastrocopta procera (Gld.)
Discus cronkhitei anthonyi (Pilsbry)
Discus shimekii (Pils.)
Helicodiscus parallelus (Say)
Hendersonia occulta (Say)
Oreohelix iowensis (Pils.)
Polygyra albolabris (Say)
Polygyra clausa (Say)
Polygyra divesta (Gld.)
Polygyra hirsuta (Say)
Polygyra profunda (Say)
Polygyra monodon (Rack)
Polygyra multilineata (Say)
Polygyra thyroides (Say)
Pomatiopsis lapidaria (Say)
Pupilla blandi Morse
Pupilla muscorum (L.)
Punctum pygmaeum (Drap.)
Pupcides marginatus (Say)
Pyramidula perspectiva (Say)
Strobilops labyrinthica (Say)
Strobilops virgo (Pils.)
Succinea avara (Say)
Succinea grosvenorii Lea.
Succinea ovalis Say
Succinea retusa Lea.
Vallonia gracilicosta Reinh.
Vallonia parvula Sterki
Vertigo bollesiana (Morse)
Vertigo elatior Sterki

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[109]Schultz, C. B., The Pleistocene mammals of Nebraska, Nebraska State Mus., Bull, vol. 1, pp. 359-360, 1934.

[110]Cameron, Cornelia, Fossils of the Peorian loess of Iowa: Thesis, Dept. of Geology, State Univ. of Iowa, 1940.

Vertigo gouldi (Binn.)
Vertigo milium (Gld.)
Vertigo modesta Say
Vertigo ovata Say
Vertigo tridentata Wolf.
Vertigo binneyana Morse
Vitrea indentata (Say)
Zonitoides arboreous (Say)
Zonitoides minusculus (Muell.)

Fresh Water Pulmonata

Fossaria parva (Lea.)
Galba caperata (Say)
Galba humilis modicella (Say)
Galba obrussa (Say)

Pelecypoda

Pisidium

The above faunal list has been compiled from 16 loess sections distributed widely over the important loess areas of the state, and permits several generalizations as to Peorian climate and vegetation.

The 56 species of gastropoda and the single pelecypod which have been identified by Cameron from the Peorian loess are all species which are living today, a representative group of which are shown in figure 67. This fact is of the greatest value in reaching a Peorian climatic interpretation for it allows a study of the ecologic variations of the modern snail fauna which can then be compared to the observed distribution of the fossil forms. This comparison has been made by Cameron, and some remarkably parallel conditions in both the distribution of species, and in the size variations (considered here as a reflection of the relative dampness or dryness of the local environment) are noted between the modern and the fossil faunas. This similarity suggests that the plant geography of the state in Peorian time was little different from that of today, except possibly for a greater admixture of deciduous and coniferous trees in the forests, resembling the present-day forests of Wisconsin and Minnesota. A constant forest-prairie relationship over the state as a whole seems to have persisted from Peorian time until the present, although the faunal profiles from the thick loess near the Iowan glacial border show a general change from deep forest conditions during early loess deposition, to forest border or prairie conditions during upper loess deposition. In a similar succession, the faunal profiles of the deep loess along the Mississippi and Missouri Rivers reflect the damp, protected, deep forest environment of early Peorian

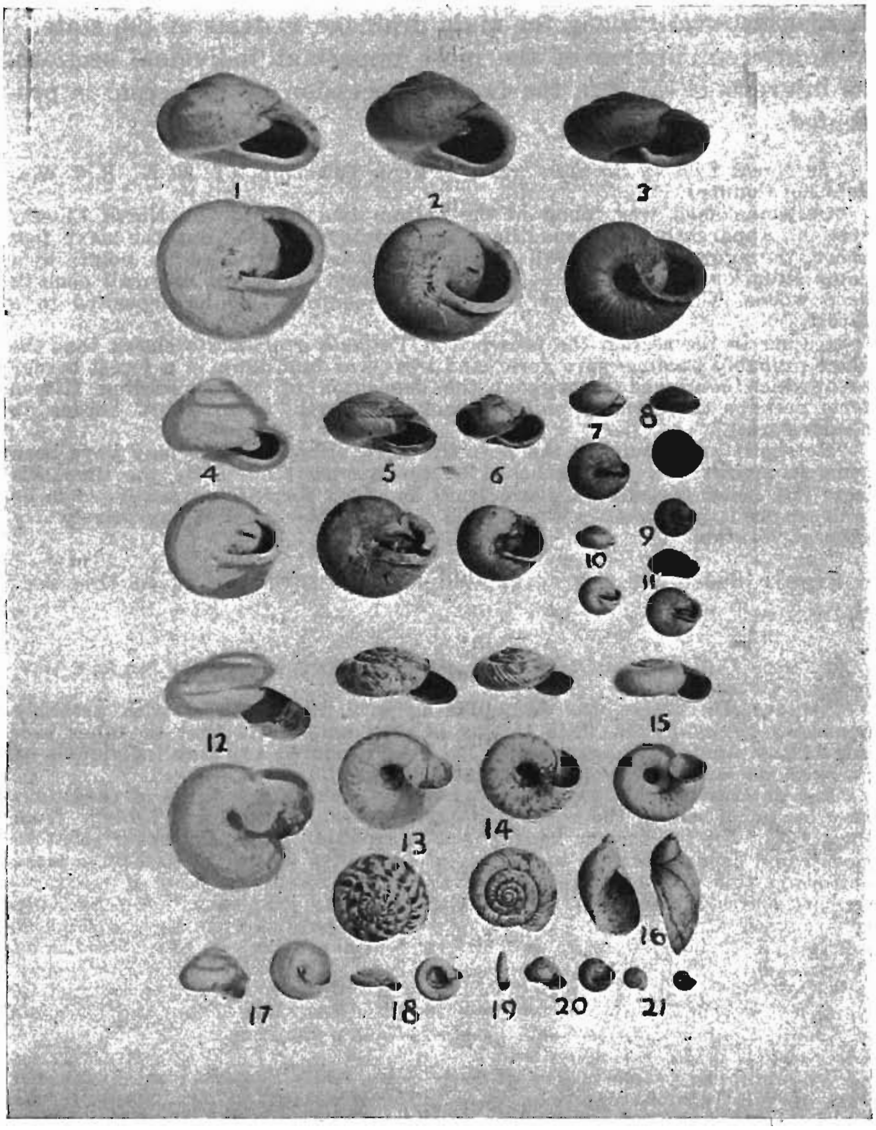


Figure 67. Terrestrial gastropods of the Peorian loess of Iowa. (After B. Shimek).

time but as the hills were built higher and the predominent westerly winds exerted a stronger ecologic influence on the flora and fauna of the forest floor, the fossils change to more xeric types, developing into the forest border and prairie fauna found in those areas today. Dense forests persisted back from the glacial border, especially along the main drainage systems of the state.

A brief discussion of the more important individual sections, as interpreted through the faunal succession by Cameron, is presented:

The North Liberty Section: (Sec. 1, Penn Township, (T. 80 N., R. 7 W.), Johnson County).

"Only one shell was found in the bottom two feet of the North Liberty section. Apparently local conditions were unfavorable. But the next foot above, the aggregation of shells among which is *Fossaria parva*, points to a damp situation which might be found at a seepy place, bog, or small pond in deep woods. The next twelve feet of loess continued to be deposited in a forest.

"Higher in the section the presence of *Vallonia gracilicosta* shows that the place probably became more xeric, and loess was laid down in a forest border area which continued throughout the deposition of the succeeding fifteen feet; perhaps there was a shifting back and forth from forest border to deeper forest.

"No shells were found in the next five feet, although there may have been some in nearby places not reached by the narrow section. By the time this loess was being deposited a distinct hill had been formed. It continued to be built up as it supported a fluctuating forest border in a comparatively dry exposed location."

Figure 68 shows the vertical distribution of fossils in this section.

The Iowa City Section: (Sec. 2, East Lucas Township, (T. 79 N., R. 6 W.), Johnson County).

"At Iowa City loess was accumulating in a deeper forest with probably numerous boggy places. This section is very unusual in that no other section in any part of the loess region has ever produced as many individuals of *Fossaria parva*, a relatively uncommon loess shell.

"It is interesting that two cuts illustrating such different sets of conditions may be found within the short distance that separates North Liberty from Iowa City. At the former locality the unfossiliferous sandy layers point to more rapid deposition than took place at Iowa City where the deposit is more uniformly fine grained. Again, there are fewer fossils per unit of measurement at North Liberty than at Iowa City. This fact coupled with the presence of *Oreohelix iowensis* and *Vallonia gracilicosta*, two shells of dry regions, at North Liberty but not at Iowa City further emphasize the xeric conditions at that place. At Iowa City, on the other hand, *Fossaria parva*, *Pupilla muscorum*, *Hendersonia occulta*, and *Polygyra multilineata* are found, but not at North Liberty in the upper forty-nine feet of loess. This group and especially *Fossaria parva* point to a more sheltered damp situation."

The Sections in Northeastern Iowa

"While the first few inches of loess were being deposited on Iowan till west of West Union conditions were unfavorable for snails. Similarly, no shells were found at the very base of the loess at the margin of the Iowan in the North Liberty section. In the remaining upper foot *Helicodiscus parallelus* occurs. This shell belongs to the group which is widely distributed over North America. It is found all over the United States and ranges northward to Manitoba where it is reported as rare.

"No fossils were found in the section east of West Union. Possibly vegetation in this area was not the type to support snail life, or perhaps their absence is due to variation in distribution.

"Shells are not abundant in the loess at the mouth of Yellow river, but those present point to a prairie which later became heavily forested. This condition remains to the present."

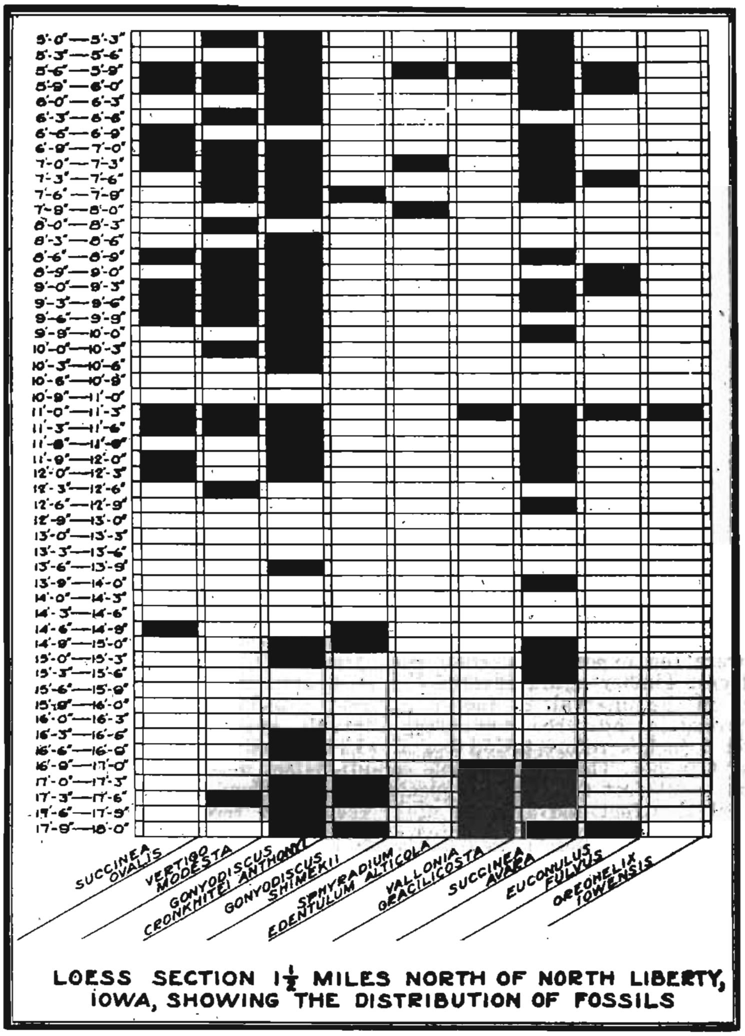


Figure 68. Graph showing the vertical distribution of fossils identified in the loess section near North Liberty, Johnson County. (After Cameron).

The Sections in Southeastern Iowa

"No shells occur in the lower one and one-half feet of loess in Wild Cat Den State Park. They are common, however, in the overlying six inches. The aggregate indicates a forest and conditions similar in the park today. Going up the section from this interval fossils become less common and of the variety which is very adaptable. It is probable that the forest floor rose gradually and continually until the present level was reached.

"As *Succinea avara* was the only fossil found in the Scott county section it is difficult to draw conclusions concerning this location. *Succinea avara* is too widely distributed both geographically and ecologically to use as a key fossil.

"The fossils of the Henry county section have a very unequal vertical distribution. None was found in material taken from six inch intervals. The six species collected were probably washed from a local pocket. With the exception of one they belong to deep woods. *Vallonia gracilicosta* is definitely a prairie species. It is likely that the loess was deposited upon a prairie which later became timbered. The region where the section was taken is wooded."

The Polk County Section: (Sec. 15, Franklin Township, (T. 80 N., R. 22 W.), Polk County).

"The section near Mitchellville in Polk county is particularly significant because fragments of wood and logs are closely associated with the abundant shells. The wood, spruce and hemlock, occurs throughout the section. Fossils taken directly from beneath logs are: *Fossaria parva, Discus cronkhitei antonyi, Polygyra monodon, Succinea ovalis* and *Vertigo modesta*. This collection indicates that the loess was laid down upon a rising succession of swampy forest floors, on seepage places, or in tiny ponds. The damp conditions must have played an important part in preserving the wood.

"The lower six inches of the section is unfossiliferous. The next interval contains only *Vertigo elatior*, a widely distributed species. In the overlying intervals the shells are those of forest species with the fresh-water pulmonate, *Fossaria parva*, occurring commonly until the depth of forty-three feet is reached. From this depth to the top of the section the shells belong to a drier forest area. The trees, probably, were of the deciduous and coniferous type similar to those of today found in northern Minnesota and Wisconsin."

Section in Washington Township, Fremont County: (Sec. 29, Washington Township, (T. 67 N., R. 42 W.), Fremont County) .

"This fifty foot section is located on the bluffs of the Missouri river in southwestern Iowa.

"The lower eleven feet of the section from 50 feet to 39 feet records a history of loess deposition in dense forest. The snails were those which thrived in rather moist heavy woods. But the conditions of the overlying five feet were too exposed for snail life. Almost no shells were collected from this loess. Timber again covered the area until a well developed forest appeared in the interval, 31 feet to 31 feet 6 inches. Another local exposure is recorded in the three succeeding intervals, but in the interval 29 feet to 29 feet 6 inches reforestation began which lasted to the interval 25 feet to 25 feet 6 inches. Then unfavorable conditions set in and not until the interval 21 feet to 21 feet 6 inches do species appear. They occur sparingly through the next five feet and are lost at 17 feet to 17 feet 6 inches. However, a dense forest developed in the interval 14 feet to 14 feet 6 inches and did not recede far during the remainder of loess deposition. There are many forest border shells from this interval to the zone of leaching."

Section in Glenwood Township, Mills County. (Sec. 12, Glenwood Township, (T. 72 N., R. 43 W.), Mills County).

"This section records a history of a well-developed forest which became more exposed and dry throughout loess deposition."

The Missouri Valley Section: (Sec. 10, St. Johns Township, (T. 78 N., R. 44 W.), Harrison County).

"The fossils in the Missouri Valley section show that the basal Peorian loess was deposited on the rising floor of a highland woods. After four and one-half feet were laid down the hill became too exposed to the dry west winds to support vegetation sufficient to feed and shelter snails. The overlying 25½ feet were deposited on a dry prairie similar to the present prairie openings on the high bluffs along the river."

The Loveland Section: (Sec. 3, Rockford Township, (T. 77 N., R. 44 W.), Pottawattamie County).

"The Loveland section is quite interesting because it contains two species, *Anguispira alternata* and *Gastrocopta armifera* which are very uncommon in the loess of Iowa.

"*Anguispira alternata* is very common in the southern loess of the Mississippi Valley, and today in Iowa the recent shells are very common and widely distributed. The animal apparently has increased its northern migration since the Peorian.

"*Gastrocopta armifera* is likewise far more common in Iowa today than as a loess fossil, but its present distribution is more widespread than that of *Anguispira alternata*.

"The fauna of this section is very typically forest border in type."

The Woodbury County Section: (Sec. 31, Union Township, (T. 89 N., R., 42 W.), Woodbury County).

"The loess in this area was deposited in an upland woods which became more xeric as the surface rose."

The horizontal change in the fauna across the state has been described in the following manner:

"If the loess fauna is traced northward and across Iowa it will practically duplicate the variations which are noted in the modern fauna. The larger species gradually disappear, and finally in much of the loess of Iowa and Nebraska only the smaller species remain, and they are largely those now living in the same area in forest border and scattered groves."

Depth of Leaching in the Peorian Loess

The Peorian interval, as previously described, in Iowa spans the time unit which in Illinois includes the Iowan loess, Tazewell drift, Tazewell loess and Cary drift. In view of the length of time represented in the deposition and weathering of Peorian loess in Iowa, and inasmuch as the loess possibly includes the two components as found in Illinois, the Iowan and Tazewell loesses, it is to be expected that a field study of the loess in Iowa would disclose minor variations in the loess. In addition, this variation due to possible differences in time of deposition may be increased by differences in loess sources, for it is evident that the Peorian loess in Iowa had not one but several source areas supplying material not completely homologous. Thus, local differences in degree to which Peorian loess of Iowa has responded to the weathering agencies are to be expected.

The most apparent change which has occurred in the loess as a whole is the surface leaching of the calcium carbonate content. The depth of leaching, as in the older Pleistocene materials previously described, is of importance in the interpretation of time relations, and tests with acid have been carried out on the loess for many years and over the entire loess area in Iowa. The average depth of leaching is about 5½ feet, which corresponds closely to the depth of leaching observed on the Iowan till, with which the Peorian loess is thought to be partly contemporaneous. This contemporaneity and the constancy of the process of leaching, whether in till or loess, would seem to be borne out by the fact that within the Iowan area, leaching in uneroded materials has progressed to a depth of about 5½ feet whether in Peorian loess, Iowan till, or thin Peorian and Iowan till. (See fig. 28, p. 108.) Thus, if a section shows 3 feet of Peorian loess on Iowan till, the till will normally be leached for 2½ feet. It has been found that in some cases, leaching of loess during a given time may be effected to a slightly greater depth than till, due perhaps to greater permeability of the loess or to an indigenous subnormal lime content in the loess. This difference, however, is generally not of measurable importance.

Beneath the Mankato drift, sections including Peorian loess show leaching to a depth of 2½ feet. The average depth of leaching of the overlying Mankato drift is 2½ feet making a total which, when the interval of actual Mankato ice occupancy is included, corresponds with marked equality with the average of leaching of surrounding loess areas. Sections of loess illustrating this depth of leaching in the Wisconsin drift areas are shown in figure 28, page 108.

It is to be noted that the thicknesses of leaching here represented for the northeastern area of the Peorian loess represent in nearly all cases the total loess thickness, with leaching of the underlying till completing the normal 5½ feet of leached material.

Thickness of the Peorian Loess in Iowa

There are great variations in the thickness of the Peorian loess in Iowa. The deepest sections are found in the counties bounding the western border of the state, along the east valley wall of the Missouri River. Here, where the wide flood-plain and persistent sand bars of the great river have maintained an ever replenished supply of dust and silt, the loess has accumulated to thickness of from 60 to 100 feet.

This extreme thickness of loess diminishes eastward, in proportion as the distance from the source increases, and in the south and central portions of the state, except for localized variations along major drainages, the loess averages less than 10 feet in thickness. Nearing the Mississippi River on the eastern border of the state, the loess thickens, but because of the prevailing westerly winds, the loess has accumulated to depths of but 10 to 15 feet on the average.

Thick loess occurs about the border of most of the Iowan drift region of northeastern Iowa, in places reaching a depth of more than 50 feet, and in general making a sharp and marked contrast

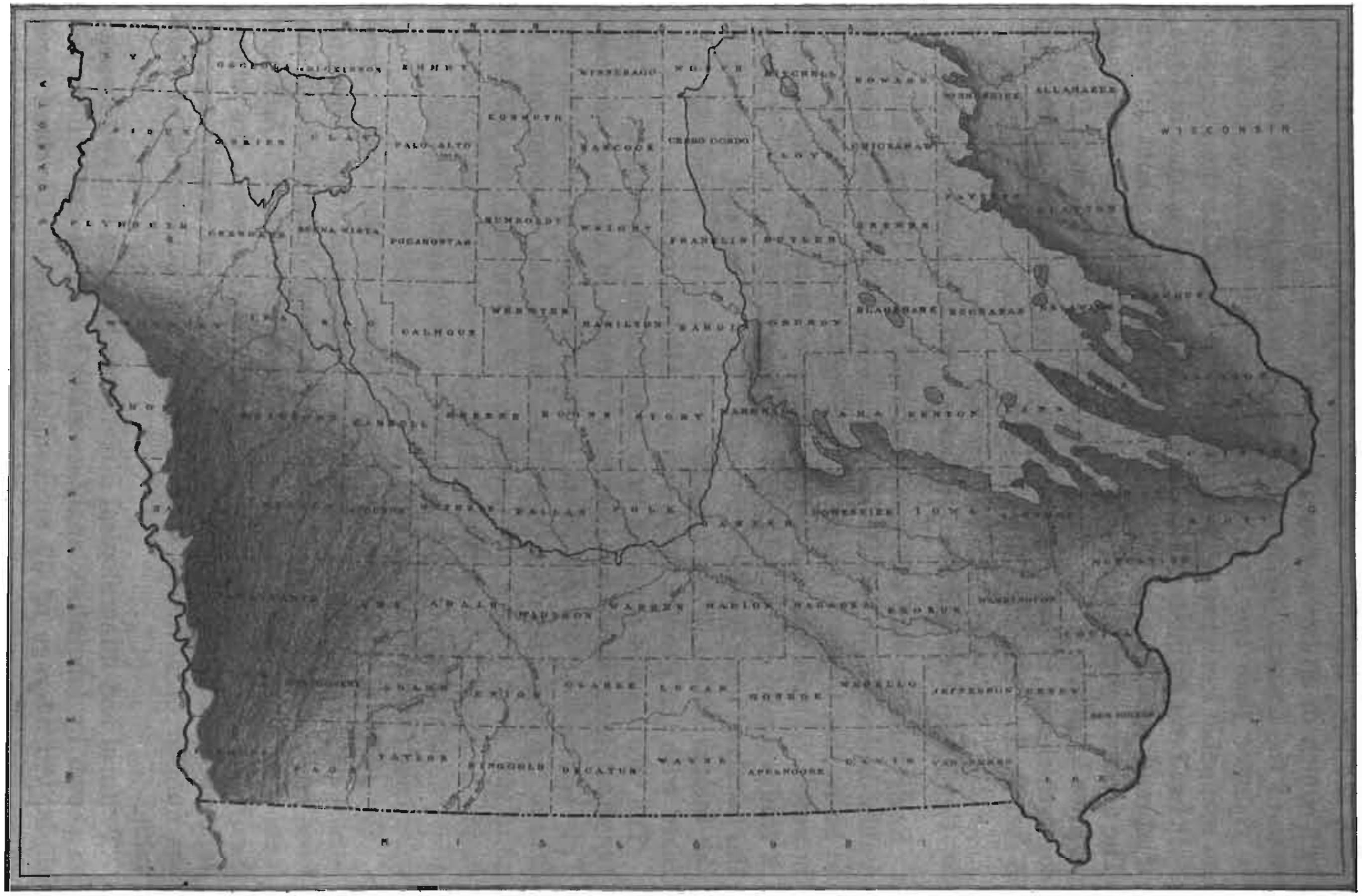


Figure 69. Map of Iowa showing relative thickness of Peorian loess by degree of shading.

with the loess thickness which is found upon the Iowan drift itself, which in all but a very few places is less than 5 feet. The area of the Mankato drift is essentially without loess, as the drift is younger than the Peorian deposit, and in this area at least, no mappable loess has been deposited subsequent to the Peorian.

It has been estimated that the amount of Peorian loess in Iowa, if spread equally over the entire state, would be about 10 feet. The accompanying map, figure 69, shows Peorian loess thicknesses in Iowa by degree of shading. Figure 70 is a map showing Peorian loess thickness in Iowa by contours. Where the loess is less than 5 feet thick, a number shows the thickness.

Comparison of the Peorian Loess With the Loveland Loess

Early workers on Pleistocene materials in the Upper Mississippi Valley believed the reddish compact loess now termed Loveland to be related to the widespread buff loess of the region. In 1909, however, Shimek published the statement that the material was of fluvio-glacial origin, related in age to the Kansan drift. Though the Loveland loess is now believed to differ in age and origin from the interpretation given it by Shimek, it has not since been confused with the Peorian loess in any published reports.

The two loesses contrast in a few striking particulars. The Loveland loess is characteristically reddish in oxidized sections. This coloration does not seem to be a feature of local nature. Where the loess is unoxidized it is bluish gray in color, and is quite similar in color to the unoxidized Peorian loess. On the other hand, the Peorian loess, when oxidized, is distinctly buff in color, and where the two loesses appear in stratigraphic sequence, the color contrast is in many places sharp and readily seen.

The fossil content of unleached sections of the two loesses serves as another guide in their differentiation. The Loveland loess is but slightly fossiliferous, and in early descriptions of the loess it was stated that the loess was barren of fossils. Although fossil mollusks are known to be present in this loess, the abundance of similar fossils in the Peorian loess so greatly exceeds the number of Loveland specimens that this evidence is of field value.

Textural and mineralogical differences between the two loesses, as shown by laboratory analyses made by Apfel and Miller, are slight. An average of 35 mechanical analyses of Loveland loess

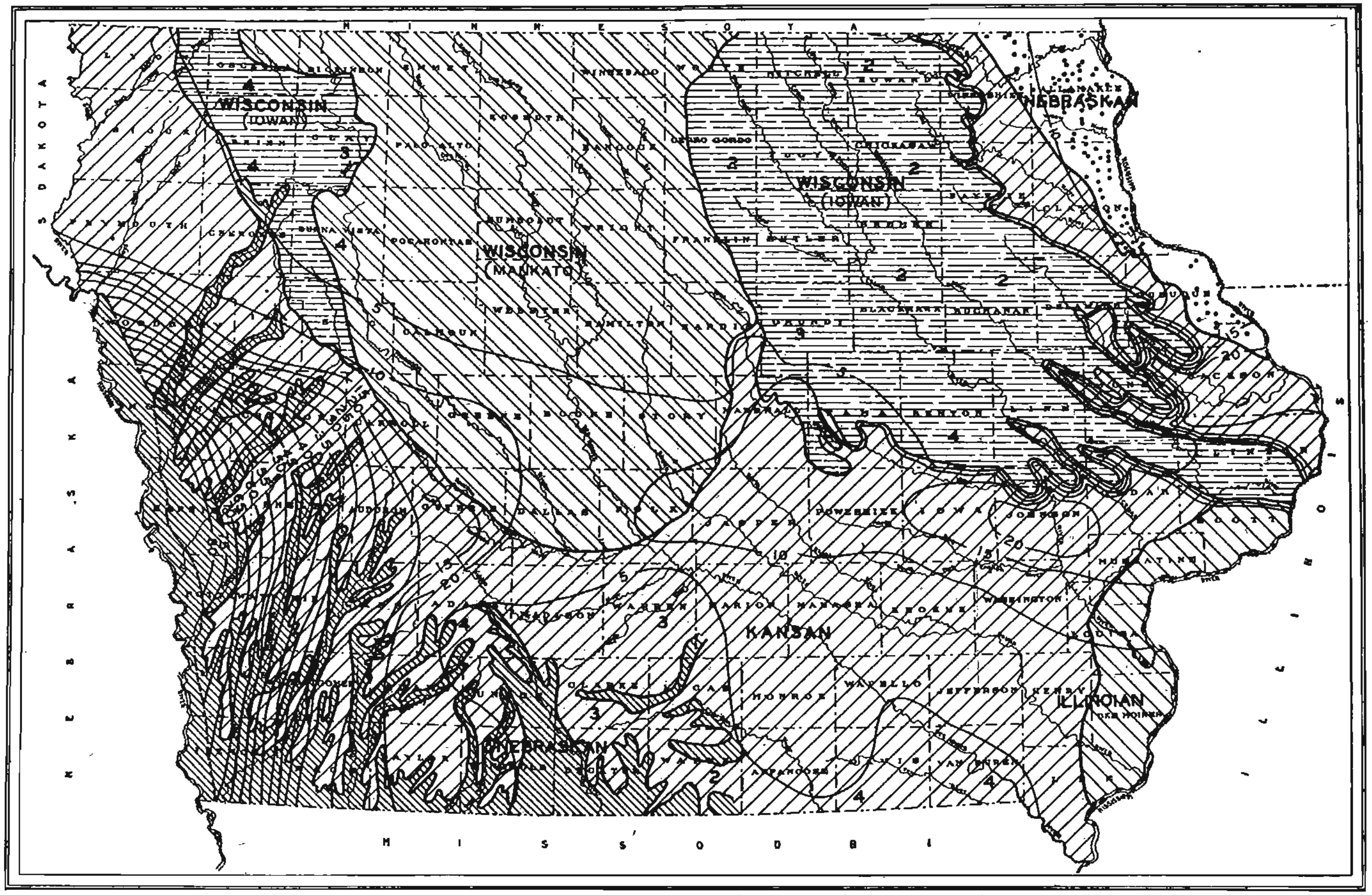


Figure 70. Map of Iowa showing the thickness of the Peorian loess by contours. Where the loess is less than 5 feet thick, a number rather than a contour shows the thickness. The contours across the Mankato area represent loess beneath rather than above the Mankato drift.

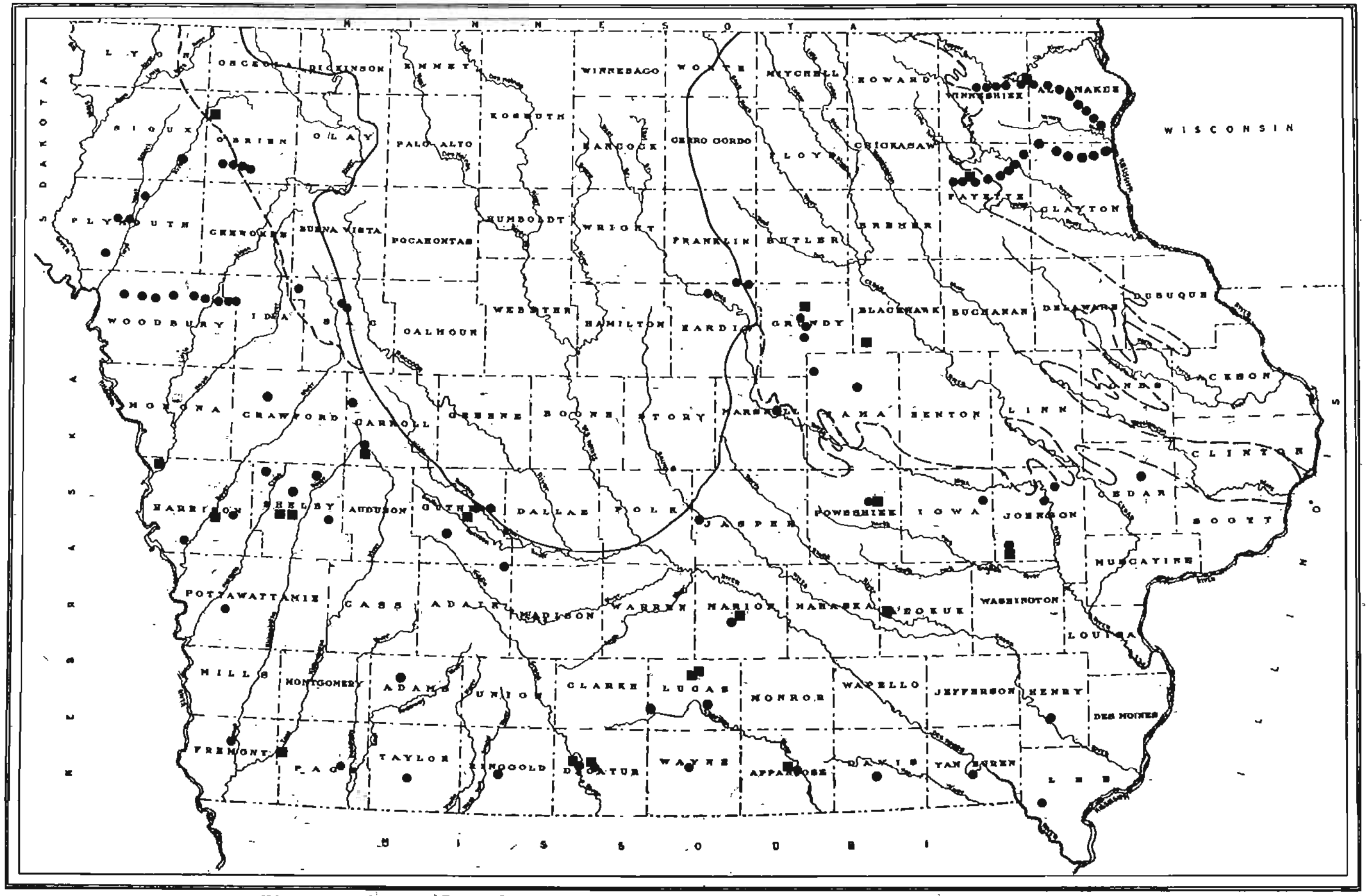


Figure 71. Map of Iowa showing locations of Peorian and Loveland loess samples collected for laboratory analyses. Squares represent Loveland locations; circles represent Peorian locations.

compared with about 50 samples of mechanically analyzed Peorian loess, collected over the state, figure 71, showed the following:

The material within the finest two size grades, those below 1/64 millimeter in diameter, show almost equal percentages for both the Loveland and the Peorian loesses, figure 72. In the next two coarser size grades the Peorian loess contains higher percentages than the Loveland. In the size grades above these, the Loveland contains the higher percentages. Some of the increase for Loveland loess, within the higher grades, is due to the iron which cements some of the finer material in some cases and forms small nodules in other cases. There is also more sand within the Loveland between 1/2 and 4 millimeters in diameter than within the Peorian.

Comparative mineralogical analyses have been made by P. T. Miller. The percentages of the major constituent minerals of the two loesses are as follows:

Mineral	Loveland loess	Peorian loess
Quartz	81.30	77.15
Undiff. Feldspar	9.82	20.36
Microcline	7.58	1.17
Plagioclase (Albite)	3.32	1.05

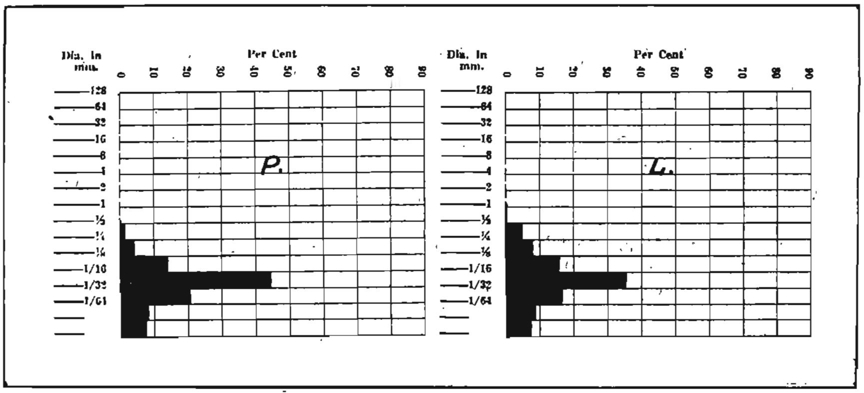


Figure 72. Graphs showing the mechanical analyses of Loveland and Peorian loesses.

The greatest percentage difference is in the undifferentiated feldspar, but this difference is not paralleled by the total percentage of feldspars in the two loesses. Neither quartz nor feldspar of one loess averages as much as 5 per cent higher or lower than the percentage of the same minerals in the other. Figure 73 shows a comparison of minor minerals.

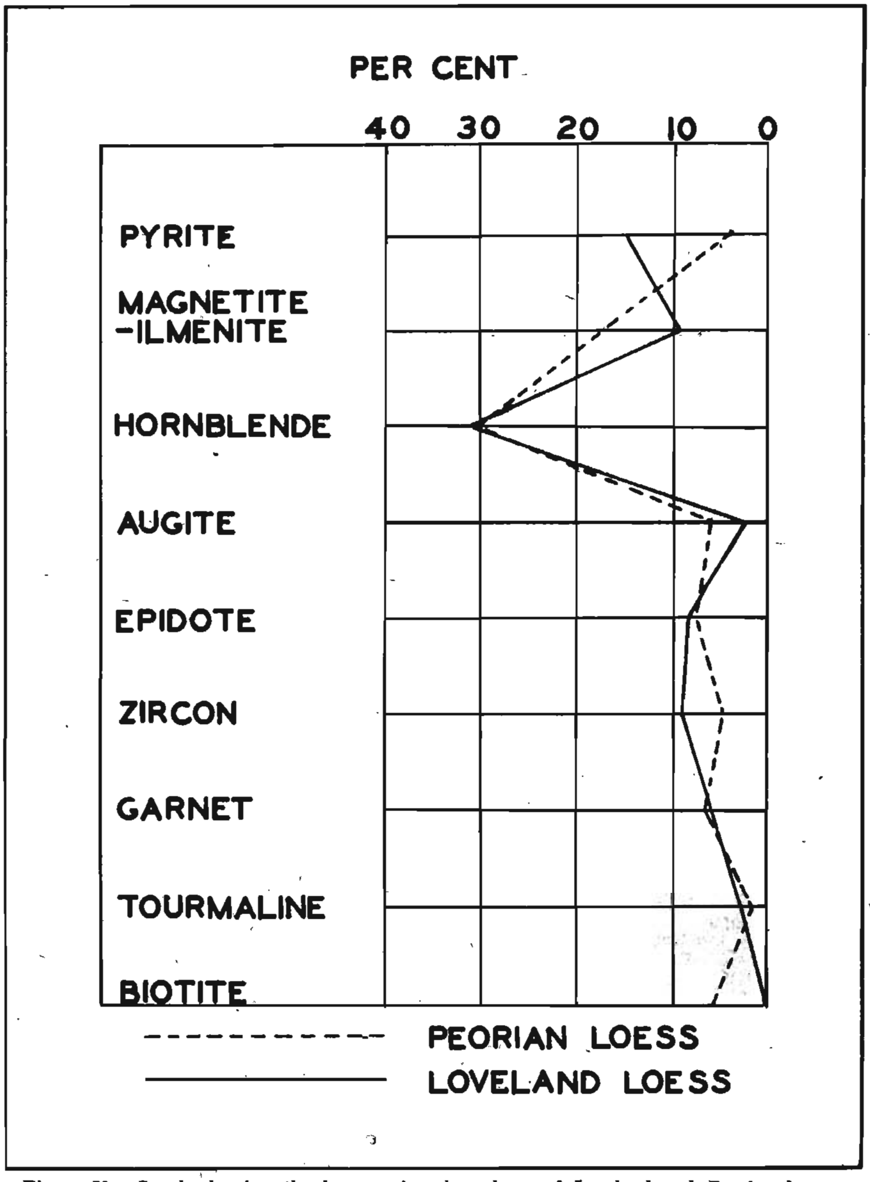


Figure 73. Graph showing the heavy mineral analyses of Loveland and Peorian loesses.

There is a considerable difference in the thicknesses of the two loesses in Iowa. The Peorian loess attains a maximum depth of 90 to 100 feet in western Iowa, and it has been estimated that if all of the Peorian loess in the state were evenly distributed over Iowa it would average about 10 feet in depth. The Loveland loess, however, rarely is found in thicknesses of more than 20 to 30 feet, It is thickest, as is the Peorian, in western Iowa. In central and eastern Iowa, sections in which Loveland loess is found show that the range in thickness is in most places a few inches up to 5 or 6 feet.

THE MANKATO GLACIAL SUBAGE (SUBSTAGE)

Discrimination of the Mankato drift
Distribution of the Mankato drift in Iowa
Origin of the drift
Changes in the drift
Typical sections of the Mankato drift
- Mankato till over loess and pre-Iowan till
- Mankato till over Peorian loess
- Exposures showing only Mankato till or gravel

Descriptions of the drift phases
- Oxidized and leached Mankato till
- Oxidized and unleached Mankato till
- Unoxidized and unleached Mankato till

The Mankato gravels
- Mankato upland gravel
- Mankato terrace gravel

Mankato morainic complex
Thickness of the Mankato drift

Following the epic work of Chamberlin and McGee in Iowa and adjacent states in the latter part of the nineteenth century, the presence of a young till in north central Iowa was recognized and generally accepted. Chamberlin, describing the drift series of the Mississippi Valley in Geikie's "Great Ice Age", in 1894, gave the name East Wisconsin to this fresh and uneroded drift sheet. Upon Upham's suggestion, the name East Wisconsin was changed by Chamberlin to Wisconsin in 1895, and this name, although with an expanded meaning, has been in general use to the present day.

It was found that in areas to the north and east of this lobe of the Wisconsin in Iowa, this drift could be separated into first two and then three distinct phases, and the terms Early, Middle and Late Wisconsin were applied to these substages, with the lobe in Iowa being recognized as the Late Wisconsin phase. It has come to be known as the Des Moines lobe of the Wisconsin, a reference to the relation of the Des Moines river valley to the drift outline and the location of the city of Des Moines at the southern extremity of the drift sheet.

In 1931, Kay[111] grouped the Iowan, Peorian and Wisconsin stages together as the last of four cycles of the Pleistocene, giving the name Eldoran to this cycle. The Iowan, however, was still considered by Kay to represent a distinct glaciation, as the evidence in Iowa indicates a short but distinct break in glacial conditions between the Iowan and Late Wisconsin drifts. In the same year, Leighton[112] in Illinois grouped the long discussed Iowan with the three previously recognized phases of the Wisconsin, making four substages rather than three for this last stage of glaciation, and thereby reducing the number of distinct glaciations from five to four. Two years later the names which are now accepted for these four substages were presented by Leighton,[113] and the name Mankato was given to the Late Wisconsin, or Des Moines lobe of Iowa. The name was taken from the town of Mankato, Minnesota, "where the Late Wisconsin deposits are excellently displayed." In a joint paper by Kay and Leighton,[114] this four-fold classification of the Wisconsin glaciation was designated as the Eldoran epoch, and with the inclusion of the Recent as the last interglacial age, the Pleistocene classification of the Upper Mississippi Valley became as it is today.

It is not unlikely that detailed study of the Wisconsin glacial substages in areas to the north may bring to light minor readvances of the Wisconsin lobes, and perhaps indicate more or less contemporaneous growth from the several centers of ice accumulation. Thwaites[115] has differentiated the Mankato substage into Early Mankato and Later Mankato. Thwaites considers the "young Red Drift" of Wisconsin and Minnesota to have come from the Patrician center, and refers to evidence indicating that the "young Gray Drift", the Mankato of Iowa which had a Keewatin source, passed over moraines of the red drift of Patrician source.

[111]Kay, G. F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 445-452, 1931.
[112]Leighton, M. M., The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley: Jour. Geology, vol. 39, pp. 45-53, 1931.
[113]Leighton, M. M., The naming of the subdivisions of the Wisconsin glacial age: Science, new ser., vol. 77, p. 168, 1933.
[114]Kay, G. F., and Leighton, M. M., Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-674, 1933.
[115]Thwaites, F. T., Outline of glacial geology, Edwards Bros. Inc., Ann Arbor, Michigan, pp. 84-85, 1934.

Discrimination of the Mankato Drift

The Mankato drift is in many respects the most distinctive of all the drift sheets in Iowa. Its youth is reflected even to the untrained eye in its undrained character, slight alteration, and the features of original deposition such as hummocks, moraines, lakes, etc. The unincised stream shown in figure 74 illustrates the youthful character of the drift. As the position of this drift is above and later than that of the Iowan and Peorian materials, the Mankato is uncovered by loess and covers the irregularly loess-mantled surfaces of the Iowan and Kansan drifts. No mappable loess has been observed on the Mankato till surface.

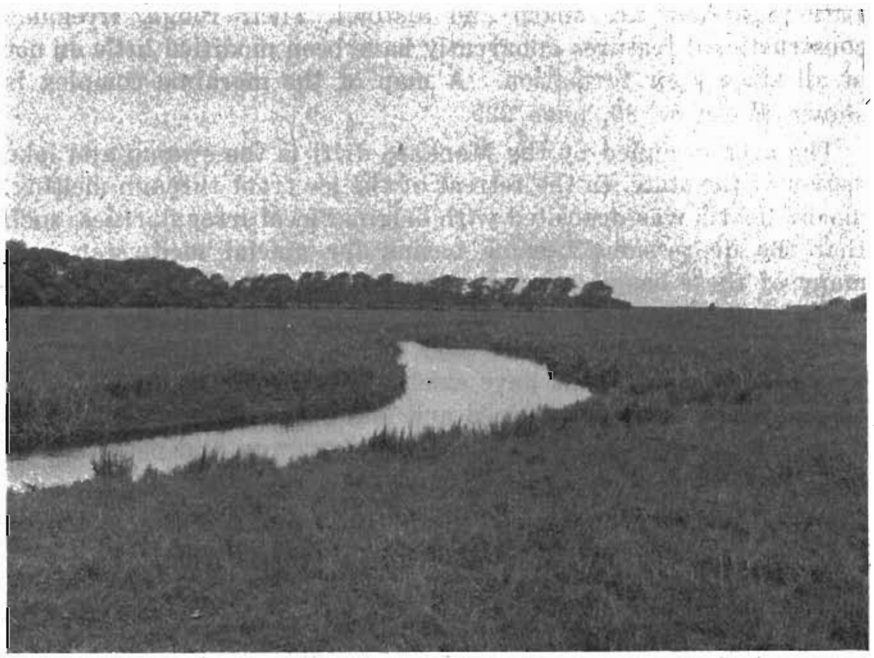


Figure 74. Stream on the Mankato drift illustrating the immature stage of erosion of the drift. Palo Alto County.

The till itself is distinctive in character. It is fresh in general appearance. It is but slightly oxidized, and alteration by leaching has occurred only in the top 30 inches on the average. No gumbotil has had time to develop, although the incipient processes leading to its production became active immediately upon withdrawal of the ice sheet. The drift materials are composed of oxidized and leached till, oxidized and unleached till, unoxidized and unleached till; silt, sand and gravel from the streams of the ice sheet, and peat deposits.

An important feature which distinguishes the Mankato from other drifts is the fact that it bears a number of well-marked moraines, lateral and recessional, along its east and west margins and across its area. A rather subdued moraine marks the western limit of the Illinoian drift sheet, but few distinctive moraines are present on the Iowan or Kansan drift surfaces. The height of land in western Iowa is probably the smoothed-out remnant of an old Kansan moraine, for here the drift is in places 500 feet or more in thickness. In contrast with these features the moraines of the Late Wisconsin are sharp and distinct. Their rough, irregular constructional features apparently have been modified little or not at all since their formation. A map of the morainic complex is shown in figure 86, page 239.

The area occupied by the Mankato drift is the swamp and lake region of the state. In the retreat of the ice front through melting, glacial debris was deposited with original local irregularities, such that the depressions became basins for glacial meltwater, and many of these basins subsequently became choked with vegetable material and have developed into the swamps and peat bogs so characterstic of the region in the days of the early settlers. However, many of the depressions have existed as lakes to the present day, and have as yet been untapped and undrained by natural processes. A sketch of the occurrence of lakes, swamps, and peat bogs in Wright County is shown in figure 75.

Distribution of the Mankato Drift in Iowa

The Mankato drift has the smallest area in Iowa of any of the drift sheets of the state, if we except the Illinoian sheet, which of course has a much greater length from its source in Labrador, and if we include that area of the Iowan sheet that now lies underneath the Mankato drift. Its lateral extent is but little over three counties or about 100 miles. The Mankato ice sheet reached into Iowa beyond the Minnesota boundary about 150 miles. Its blanket of drift occupies 14 entire counties and parts of 15 others, a total area of approximately 11,540 square miles, about one-fifth of the total area of the state. Figure 76 shows the areal extent of the Mankato drift in Iowa.

The Mankato drift sheet in Iowa is usually called the Des Moines lobe of the Late Wisconsin, and an inspection of a glacial map of the Upper Mississippi Valley will show that it is one of several such lobes, a similar lobe in South Dakota being known as the James River lobe. While the Des Moines lobe occupies the river valley of that name it is doubtful if the valley had any great effect in determining the location, direction or limits of the tongue of ice that extended out from the main glacier. The map shows also that with one exception the margin of the lobe is fairly smooth and straight. This exception is a great indentation in northwestern Iowa, occupying parts of Osceola, Dickinson, Clay and O'Brien Counties. The reason for this indentation is not very clear.

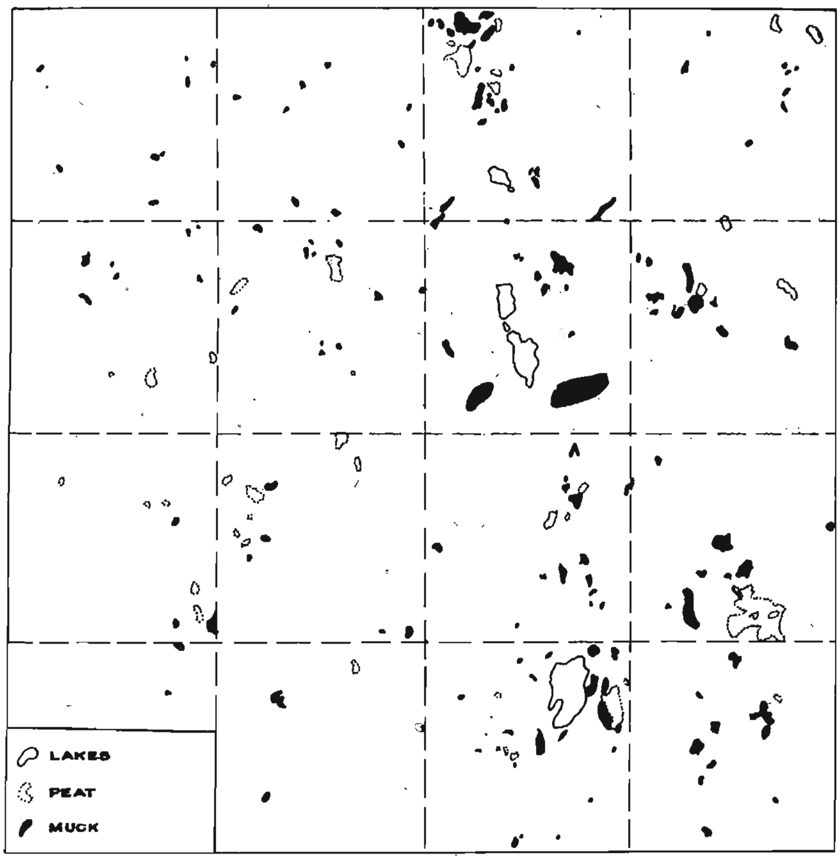


Figure 75. Sketch map of Wright County showing peat, muck and lake areas on the Mankato drift plain.

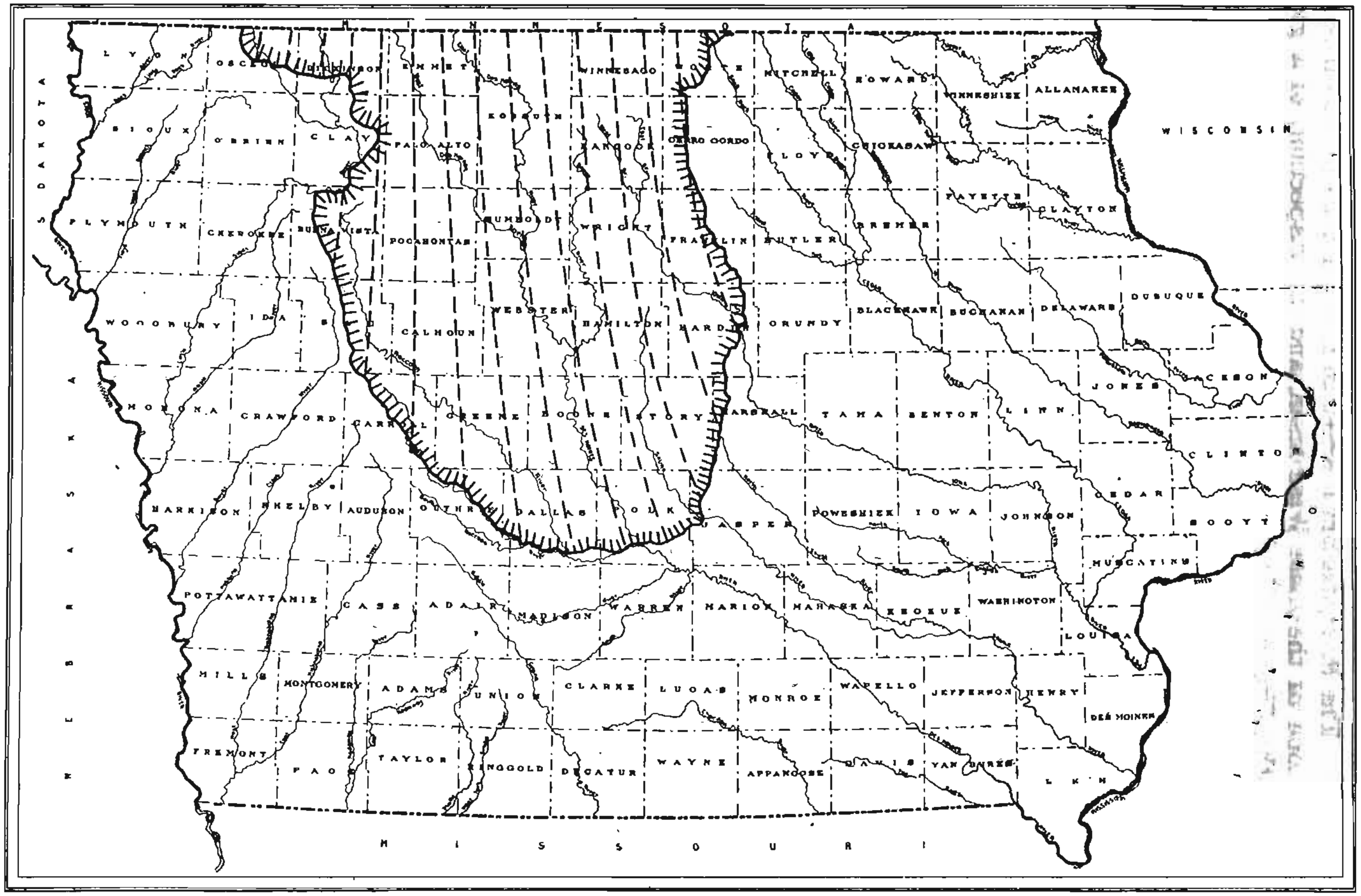


Figure 76. Map of Iowa showing the extent of Mankato glaciation.

The Mankato drift lobe in Iowa is bounded on both sides along the northern area of the state by Iowan drift. Lateral and terminal moraines quite sharply delimit the Mankato from the gently rolling, drift-mantled erosional Iowan topography of northeastern Iowa, as well as from the Kansan-like Iowan topography on the west. The Mankato lobe spread deeper into the state than did the Iowan, overlapping the Iowan and extending out onto the Kansan drift.

Origin of the Drift

The Mankato drift is typical unconsolidated glacial material, composed principally of light colored oxidized till and bluish unoxidized till. Outwash sand and gravel deposits occur around the periphery of the lobe and to some extent on the till surface, having been deposited by streams flowing outward from the retreating glacier.

The drift materials were derived from regions to the north of Iowa and from the incorporation of local material by the Mankato ice. The Mankato lobe in Iowa is a tongue of a continental ice mass originating from the Keewatin ice center to the west of Hudson Bay in Canada. In its extension into Iowa the ice moved over bedrock and former drift surfaces, bringing into Iowa materials gouged directly from bedrock, and materials which had already been glacially transported perhaps several times by former glaciers. Within the state the glacier overrode a surface variously composed of Peorian loess, Iowan drift and Kansan drift. In places, the Peorian loess surface beneath the Mankato till shows plowing action and indicates some loess incorporation into the till. Such an occurrence is prominent in the Mitchellville cut, located in the NE¼ sec. 15, Franklin Township, (T. 80 N., R. 22 W.), Polk County, and previously described on pages 169 to 171 of this report. The section shows a considerable amount of Peorian loess intermixed with the thin Mankato till. However, good sections showing the contact of the Mankato drift with underlying materials are rare due to the flat character of the topography and the consequent lack of deep railroad and highway cuts.

Contrary to the theoretical possibility that the materials of this last of the known North American glacial advances would be so largely composed of rehandled surface drift materials that it would reflect unusual weathering, the till is fresh and unaltered except for about 2½ feet of the upper part which has been leached since the Mankato retreat. Some crumbly boulders are found in the fresh till, and these may well have lain at or near the surface of a former drift sheet, but their percentage is not such as to contrast markedly with similar occurrences in the older drifts.

Changes in the Drift

The Mankato drift materials are so recent in deposition that physical and chemical processes of weathering and alteration have been able to change the original till character only slightly. In the judgment of many glacial geologists, the Recent, or time since the retreat of the last glacier is but the beginning of conditions similar to previous interglacial ages, and it is considered probable that the present moment of geologic time is a stage in the gradual recovery from glacial conditions and just antecedent to the mild, comparatively stable interval of a typical interglacial age. There are convincing arguments in support of this view of our present position in the Pleistocene period.

Principally through the work of DeGeer and Antevs on Pleistocene geochronology, estimates as to the antiquity of the last continental glacier in Europe and North America have been generally accepted as about 25,000 years. Geologically speaking, this interval is extremely short, and in comparison with estimates of other intervals of weathering during the Pleistocene[116] it becomes apparent that the effects of weathering agencies, if such agencies react with similar rapidity under similar climatic and topographic conditions, cannot have produced any changes in Mankato till comparable in degree to the changes previously discussed in relation to the older drifts. That this generalization is substantiated in the field is not difficult to demonstrate. Erosion has as yet scarcely touched the depositional forms of the recently deposited Mankato drift. Oxidation, always the first agent to attack and alter the physical appearance of fresh, bluish till, has changed the till to a light gray-buff color to various depths, but nowhere have the materials acquired the old, rusted and iron-cemented appearance of the tills and gravels which have been subjected to much greater periods of oxidation. Leaching and other chemical processes which were active for long enough intervals to have caused the formation of an inactive residuum or gumbotil in places on the

[116]Kay, G. F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 425-466, 1931.

three oldest tills, have only removed the carbonates from the Mankato till for a depth of about 30 inches on the average. No gumbotil has been formed and presumably will not be formed until leaching and other chemical changes have taken place to a depth somewhat greater than that on the Iowan drift, which averages about 5½ feet. The profile of weathering as found on the three oldest drifts is in a most immature stage on the Mankato till.

Typical Sections of the Mankato Drift

The generally level character of the Mankato drift surface tends toward scarcity of cuts along the roads and toward shallowness of those that need to be made. Satisfactory exposures of drift along the stream courses also are rather uncommon. However, a number of cuts over the Late Wisconsin area show several feet of Mankato till; some extend into the underlying Iowan loess and a few even reach below into the subjacent drift sheet. In each case this drift was shown to be Kansan or older, either by its geographic location, by its character, or by the presence of its overlying gumbotil.

Mankato Till Over Loess and Pre-Iowan Till

Naturally the best exposures showing older till under Mankato are near the margin of the later till sheet. One very good section of this nature was exposed in 1920 during the cutting to a lower grade of West Fifth Street in Des Moines.[117] This section showed:

	Feet	Inches
"5. Till, Wisconsin, (Mankato), oxidized to brownish clay, bouldery, many limestone	6	
4. Loess, Iowan, calcareous, chiefly yellow, locally gray in upper part, the latter marked at its base by a ferruginous band. Yellow phase fossiliferous in places, red 'pipe-stems' in gray phase. Maximum thickness	18	
3. Till, Kansan, leached, red brown, sticky, in most places pebbles few and very small, when dry hard with starchy fracture	7	
2. Till, Kansan, leached, oxidized to yellowish, boulders, some red fresh granites	6-10	
1. Shale, Des Moines, variegated."		

Lees states:

"In the vicinity of Crocker Street there are in the upper portion of the loess several small sand lenses about four feet long and six inches thick. They . . . . are surrounded by the gray loess except where they rise to the surface of this stratum and come in contact with the overlying till. These lenses were stated by Keyes to be largely volcanic ash."[118]

[117]Lees, James H., Some Pleistocene exposures in Des Moines: Iowa Acad. Sci., vol. 28, p. 60, 1921.
[118]Keyes, Charles R., Discovery of volcanic ash in Iowa: Iowa Acad. Sci., vol. 28, p. 49, 1921.

A smaller section with similar range was seen in the bluff forming the north wall of Des Moines valley south of the State House in Des Moines. The succession here observed at the mouth of a ravine was:

	Feet	Inches
Mankato glacial substage:		
Till, pebbly. Thickness variable.		
Peorian intraglacial substage:		
Loess, yellow and soft above, gray and hard in lower foot or two, lime concretions throughout, shells, sand grains in basal part	7	
Kansan glacial stage:		
Till, red below, gray and calcareous in upper foot, pebbly	4	
Bedrock:		
Sandstone and shale, Des Moines; exposed	12	

The series of cuts west of Rhodes (fig. 77), in Marshall and Story Counties, on the Omaha line of the Chicago, Milwaukee, St. Paul and Pacific Railroad, showing Mankato till over loess and this in turn over Kansan gumbotil and till has been already described by Kay and Apfel and by Alden and Leighton.[119] These cuts probably give the best exposures of this kind that have ever been found in the state. They are just within the Late Wisconsin margin and represent the work of the Mankato ice at its extreme advance. Another section that is well within the limits of the Mankato drift sheet is on the south bank of Raccoon River in the N½ sec. 27, Grant Township, (T. 83 N., R. 30 W.), in Greene County. When this section was examined it showed good exposures from top to bottom of the high bluff. The section as examined included the following members:

	Feet	Inches
Mankato glacial substage:		
Till, oxidized and leached, yellow, some sand streaks, in places breaking into great prismatic blocks	4	
Till, oxidized and unleached, yellowish gray, with some large gravel boulders	20	
Till, unoxidized and unleached, dark gray	20	
Peorian intraglacial substage:		
Loess, gray or brown above, becoming yellow on exposure, unleached, but no fossils or concretions. Some shows joint structure and rust-red color on joint faces. Lower part is blue, abundantly fossiliferous locally. Loess rises 40 feet above river and is sharply marked from the Mankato till	6-20	
Buchanan interval:		
Gravel, in places, rusty, red and yellow, some layers fine sand, some sand and silt, some coarse gravel;		

[119]Kay, G. F., and Apfel, E. T., The pre-Illinoian Pleistocene geology of Iowa: Iowa Geol. Survey, vol. 34, p. 233, 1929.
Alden, Wm. C., and Leighton, M. M., The Iowan drift, a review of the evidences of the Iowan stage of glaciation: Iowa Geol. Survey, vol. 26, p. 161, 1917.

Figure 77. Wisconsin till of Mankato age overlying Peorian loess in Chicago, Milwaukee and St. Paul Railway cut southwest of Rhodes, Marshall County.

grades into loess above; one granite boulder 4 feet in diameter in the gravels, also several smaller ones apparently at contact with loess	4-10
Kansan glacial stage:	
Till, yellowish brown above, blue or very dark gray grading down to nearly black below; hard, pebbly, jointed; exposed above river level	6-20

The lower till is classed as Kansan because it is south of the probable margin of the Iowan. It is darker than the lower part of the Mankato as exposed above the loess, and it shows rather more definite jointing. This is one of the best sections in the area of the Late Wisconsin drift.

Several other exposures are known in which Mankato drift lies on much older materials. One of these is in the pit of the Fort Dodge Brick and Tile Company in the northern part of Fort Dodge, sec. 19, Wahkonsa Township, (T. 89 N., R. 28 W.), Webster County. It shows above the "Coal Measures" shales a layer of gray gumbotil, then gray Mankato till, then 12 feet of yellow Mankato till, and at the surface 3 feet of gray gravel. Again, at the highway bridge over the West Fork of Des Moines River about a mile south of Bradgate, in the northwest corner of sec. 17, Avery Township, (T. 92 N., R. 30 W.), Humboldt County, undercutting and road grading have exposed 20 feet of yellow, very pebbly Mankato till, 5 feet of rather fine fresh gravel and 20 feet of drab, sparsely pebbly drift, the upper part of which is altered to gumbotil. The gumbotil is shown again 100 yards down stream and about 10 feet above the water.

Since the Kansan gumbotil is thought to be absent north of Crawford County, while the Nebraskan gumbotil is known to be present in Cherokee County, 55 miles west of Bradgate, it seems most probable that the Bradgate outcrops of gumbotil and till are Nebraskan in age. Their altitude is about 1100 feet, while the altitude of the Nebraskan gumbotil at Cherokee is 1235 feet and that at Coon Rapids, 65 miles south, is 1180. On the other hand, the Kansan gumbotil at its farthest known northward exposure, along the Chicago and North Western Railway track in the northwest corner of sec. 9, Stockholm Township, (T. 85 N., R. 38 W.), Crawford County, lies 1400 feet above sea level. In other parts of Crawford County the Kansan gumbotil has been seen as high as 1485 feet above sea level. These facts seem to render improbable a Kansan age for this gumbotil at Bradgate, and the same argument applies to that seen at Fort Dodge. This lies 75 feet above the river, but its elevation is only about 1050 feet above sea level.

One other good section showing drift materials ranging in age from late Wisconsin to Kansan was opened in the course of road grading on State highway 64 (formerly 7) west of Panora at the middle of the north line of sec. 6, Cass Township, (T. 80 N., R. 30 W.), Guthrie County. (See fig. 53, p. 172). Along the slope of the valley wall the cuts showed this succession:

	Feet	Inches
Mankato glacial substage:		
Till	3	
Peorian intraglacial substage:		
Loess, yellow, generally fresh to contact with Mankato till, but locally upper foot is leached	8	
Kansan glacial stage:		
Till, strongly oxidized, leached	5	6
Bedrock:		
Shale, Des Moines, reworked, exposed	7	6

In places Mankato gravel, rusty but unleached, overlies the loess. At the upland, Kansan gumbotil is on the Kansan till. This cut is just at the margin of the Mankato drift sheet and shows the westernmost push of the late Wisconsin ice for this locality.

One of the famous cuts of an earlier day was that of the Chicago Great Western Railway just northeast of Carroll, in sec. 19, Grant Township, (T. 84 N., R. 34 W.), Carroll County. This exposure showed:

	Feet	Inches
Mankato glacial substage:		
Till, oxidized, unleached	3-12	
Peorian intraglacial substage:		
Loess, buff with gray patches	12	
Loveland interval:		
Loess, gray, leached	3	
Kansan glacial stage:		
Gumbotil, chocolate colored, upper part modified	2	6
Till, oxidized and leached, grading up into gumbotil	3	
Till, oxidized and unleached, yellow, concretions	22	

The elevation of the gumbotil is 1275 feet above sea level.

Another exposure of Mankato till and Peorian loess over Kansan gumbotil was seen in Dallas County, in the NW¼ sec. 4, Colfax Township, (T. 79 N., R. 28 W.).

A good section, from which, however, the Kansan gumbotil had been removed, is in southern Hardin County, in the SE¼, sec. 6, Providence Township, (T. 86 N., R. 20 W.). It showed:

	Feet	Inches
Mankato glacial substage:		
Till to the upland, over	20	
Peorian intraglacial substage:		
Loess, calcareous, approximately	15	
Kansan glacial stage:		
Till, highly oxidized, to base of slope, approximately	10	

This series of sections shows that at least in the southern part of its extent, the Mankato ice sheet, while it overrode the Peorian loess, did not greatly disturb it. This loess must have been leached through not much more than 2 to 3 feet of its thickness, on the average, and in most cases this leached part, together with an unknown amount of unleached loess was scraped off by the advancing ice.

Mankato Till over Peorian Loess

In a few cases the Mankato till is thin enough so that in the making of road grades it was cut away and the loess that underlies it was exposed but not entirely penetrated so that the underlying till could be seen. One of these cases is a road cut in the NW¼ sec. 12, Boyer Valley Township, (T. 88 N., R. 36 W.), in Sac County, about 2 miles east of Early, on the east wall of Indian Creek Valley. Here the Mankato till is about 12 feet thick and is fresh within 2½ feet of the top. It lies on loess, which is plowed up to some extent. This loess is yellow but unleached and carries concretions. Evidently the late Wisconsin ice or waters cut away the leached loess and mingled gravel and fresh Peorian loess in the lower part of the Mankato till sheet. The thickness of the loess is unknown as only about 2 feet is exposed above the slump.

A series of sections in glacial materials on Capitol Hill in Des Moines that was described in 1882 by McGee and Call[120] made this locality famous as helping to demonstrate the plurality of the ice sheets. While these sections did not actually show two drifts they did show a thick body of loess underneath Mankato till. When the grade of East Court Avenue was lowered through the State House grounds in 1915 the locations of McGee and Call's sections were cut through and abundant opportunity was given for extensive study of the beds capping the hill. Several sections were carefully studied by Lees[121] and one of the most typical is given here:

[120]McGee, W J, and Call, R. E., On the loess and associated deposits of Des Moines: Am. Jour. Sci., vol. 24, pp. 202-223, 1882.
[121]Lees, J. H., The Pleistocene of Capitol Hill: Iowa Acad. Sci., vol. 23, pp. 167-172, 1916.

		Feet	Inches
"12.	Till, Wisconsin (Mankato), weathered, brownish	3	
11.	Till, Wisconsin (Mankato), buff, pebbly, grades into No. 12	5	
10.	Till, Wisconsin (Mankato), gray, pebbly, grades into No. 11	4	
9.	Till, Wisconsin (Mankato), gray, alternating with sand streaks	2	
8.	Loess, Iowan (Peorian), gray and buff, shells abundant	1-2	
7.	Clay, buff, sandy in places, abundant pebbles, mostly rather small, some up to two inches in diameter, a few six or eight inches, fresh limestones, quartz, greenstones, and granites, some disintegrated. Shells of loess types abundant in places. Between this member and No. 8 are rolled masses of gray loess with concentric laminations	2-3	
6.	Clay, brown, jointed, loess shells abundant, no pebbles, probably a weathered loess	1	6
5.	Loess, gray, shells abundant	1	
4.	Loess, buff, fossiliferous	3	
3.	Loess, gray, fossiliferous	1	
2.	Sand, in lens at least 100 by 150 feet, fine, yellow with brown streaks; crossbedded	2-6	
1.	Loess, fossiliferous, gray in upper foot, grading down to buff, some masses of blue	10"	

The total thickness of the loess must be about 20 feet. Below it were exposed geest, residual from the Des Moines shales, and about 15 feet of the unaltered shales. No pre-loessial till was seen in any of the exposures. The clay, no. 7, was remarkable in being so abundantly fossiliferous and at the same time pebble-bearing. It seems to have been a mixture of till and loess, probably laid by waters from the ice. It is to be noted that this exposure is at the extreme edge of the late Wisconsin drift sheet.

Gray Peorian loess was reached also three blocks north of these cuts, in the excavation through late Wisconsin till made in 1920 for a heating plant tunnel to the State House. Similar loess was found in the excavation for the new East High School building four blocks farther north.

Exposures Showing Only Mankato Till or Gravel

Naturally there are, distributed over the area of the Mankato drift sheet, numerous shallow exposures of late Wisconsin materials, either till or gravels or both. These differ merely to a minor degree in character of material and depth of leaching, and their general accordance testifies to the uniform conditions to which they have been subjected and the uniform results attained.

A series of sections in Dallas County seems to show the effect of the character of material on the range of leaching in the till.

An opening in the SE¼ sec. 5, Walnut Township, (T. 79 N., R. 26 W.), was made to obtain gravel. It exposed:

	Feet	Inches
Mankato glacial substage:		
Loam, leached, black	1	2
Till, brownish yellow, very gravelly, abundant coarse limestone pebbles, clay matrix also very limy to the soil; transition from black to yellow abrupt; exposed	4	

The slopes are very gentle and suggest that very little erosian can have occurred. The section seems to show that where till has much limestone it is leached very slowly, and hence this process has not gone very far downward.

Another section was observed on the north side of the NE¼ sec. 2, Linn Township, (T. 79 N., R. 29 W.). It consisted of:

	Feet	Inches
Mankato glacial substage:		
Loam, leached, black	1	
Till, leached, dark brown, few pebbles	1	
Till, leached, lighter yellow in lower part	1	9
Till, unleached, yellow; exposed		6

This cut is at the upland where erosion must have been very slight. The till is somewhat sandy.

The third section in this series is a road cut in the NE¼ sec. 7, (T. 79 N., R. 26 W.), and it showed:

	Feet	Inches
Mankato glacial substage:		
Loam, black sandy, leached	1	
Till, leached, sandy, dark brownish yellow	2	
Till, leached, yellow, sandy; has a few small limestone pebbles and secondary lime concretions about 4 inches above the unleached till	1	
Till, unleached.		

This cut also is near the upland and the slopes are very gentle. The leaching of 4 feet is somewhat greater than normal and may be due to the sandy and porous nature of the till, which would permit free percolation and relatively rapid leaching. A number of other sections in this part of the state show similar features.

A road section in the SE¼ sec. 33, Fremont Township, (T. 89 N., R. 26 W.), Hamilton County, seems to show the effect of composition and texture on weathering. It is as follows:

	Feet	Inches
Mankato glacial substage:		
Loam, sandy humus, leached		6
Till, sandy, brown, leached	3	
Till, unleached; exposed	1	

This exposure is out on the level Mankato plain and should be typical for the type of deposit represented.

Two sections in Calhoun County are of interest as showing similarity of change in different materials. The first exposure is in the SE¼ sec. 4, Williams Township, (T. 89 N., R. 34 W.). It is a pit in Mankato upland gravels and reveals:

	Feet	Inches
Mankato glacial substage:		
Loam, sandy, gravelly, black	1	
Gravels, brown, leached to 27 to 31 inches from surface; about	1	6
Gravels, light colored, much limestone; exposed	8	

The other section is a road cut in the SW¼ sec. 34, Garfield Township, (T. 88 N., R. 34 W.), and is in normal till. It is as follows:

	Feet	Inches
Mankato glacial substage:		
Loam, black, leached	1	
Till, yellow, oxidized, leached, some pebbles; about	1	6
Till, oxidized, unleached, gray and yellow; exposed	2	

In these cases the very limy gravels and the normal limy clay have suffered leaching to about the same depth. Both exposures are at the upland and have been subjected to similar conditions.

Several roadside cuts within a mile south of Eagle Grove in Wright County show till which is leached from 3 feet 4 inches in normal till to 5 feet in sandy till, and a cut in the southwest environs of Fonda, (T. 90 N., R. 34 W.), in Pocahontas County, shows what seems to be more nearly the average of 2½ feet of leached material. This exposure shows normal compact pebbly clay till which is leached 31 inches but still contains pebbles nearly up to the sod. This locality is on the upland where there can have been neither erosion nor deposition since the drift was brought in.

A gravel pit in the east part of Mason City, Mason Township, (T. 96 N., R. 20 W.), Cerro Gordo County, seems to bear out the view that gravels containing much limestone do not leach so rapidly as do clays with very little lime, but with much siliceous sand, despite the greater porosity of the gravel. This pit shows a sandy, pebbly, leached loam with a thickness of 1 foot 3 inches, below which are fresh gravels filled with limestone pebbles. Similar features are shown in outwash gravels in the southeast corner of sec. 17, and the north part of sec. 28, Kensett Township, (T. 99 N., R. 20 W.), of Worth County. Pits in these gravels show that leaching has progressed to a depth of 2 feet 10 inches and 2 feet 6 inches respectively. A number of road cuts in the northern counties of the late Wisconsin area show a general uniformity in leaching of soil and till to a depth of about 2½ feet. A series of such cuts in the SW¼ sec. 11, Swan Lake Township, (T. 99 N., R. 32 W.), Emmett County, shows a range from 2 feet 4 inches to 3 feet 3 inches. Since topographic conditions are similar at all cuts this difference seemingly is attributable to different composition of the till.

Most of the sections in the Mankato area are too shallow to uncover a great thickness of the Mankato till. The following section made along the north wall of the Des Moines River Valley in the SW¼ sec. 12, Cresco Township, (T. 95 N., R. 29 W.), Kossuth County, just south of Algona, shows more Mankato till than is commonly seen:

	Feet	Inches
Mankato glacial substage:		
Loam, sandy, with humus		6
Till, leached, on surface light brown, at depth brown to chocolate color, pebbly	2	6
Till, unleached distinctly oxidized, light yellow to yellowish gray on dry slope, yellow to brownish on fresh surface; cuts readily, not compact	6	
Till, unoxidized and unleached, but oxidized along joints. Inclusions of sand are oxidized. To base of cut	16	
(In the oxidized and unleached zone there are inclusions of loess).		
Down the slope toward the flood plain very dark unoxidized and unleached Mankato till was exposed. The flood plain is 64 feet below the upland.		

Description of the Drift Phases

Oxidized and Leached Mankato Till

Under normal conditions of topographic stability and interglacial weathering processes, a profile of weathering will develop in till materials, the completeness of this profile depending primarily upon the length of time during which the agents of weathering are free to act. Three of the drift sheets in Iowa have been exposed to weathering agents a sufficient length of time to have developed mature profiles of weathering, with all of the till phases present, differing from one another only in the degree of depth to which the various phases have been formed.

The Mankato drift is the youngest substage of the last glacial age, and as such has not been exposed to agents of weathering long enough to have acquired a mature profile of weathering. No gumbotil has been formed, and leaching has as yet changed only the upper 30 inches on the average. Oxidation has penetrated to a greater depth than leaching, but the lightness of color of the till attests the incompleteness of oxidation of the content of iron compounds in the till.

The topmost phase of the Mankato till, except for occasional areas of peat and humus, is the oxidized and leached phase which except for the Iowan, occurs below gumbotil on the older drifts. This zone is light brown in color, or may be chocolate brown where present day humus material has penetrated. Leaching has removed the carbonates to depths ranging from 2 to 5 feet, with an average depth of 2½ feet. The till is pebbly to sandy and is not compact.

The clastic texture of the oxidized and leached Mankato till is so much like that of the oxidized and leached Iowan till that a comparison of an average analysis of each shows almost no differences. The analyses of the averages of the two ages of till are more nearly identical than one would expect to find even within two samples of till from either till sheet (fig. 6, p. 34). In the average analysis of the Mankato oxidized and leached till, the maximum percentage of material, about 28 percent, is finer than 1/64 millimeter in diameter. The size grade between 1/32 and 1/64 millimeter in diameter contains about 9 percent or only about 30 percent as much material as the grade below 1/64 millimeter in diameter, and the size grade between 1/16 and 1/32 millimeter in diameter shows an increase to 15 percent or about 50 percent as much as that size grade finer than 1/64 millimeter in diameter. As in the Iowan till, the greatest percentage of the sample is within the size grades between 1/2 and 1/32 millimeter in diameter.

The lithology of the Mankato oxidized and leached till (fig. 78) has only one point of difference of importance from that of the Iowan oxidized and leached till: it is the low percentage of greenstone and the high percentage of granite. All of the other constituents are almost in the same percentages.

Processes of weathering have disintegrated some of the material and solution has rounded some of the grains. The shapes of the grains of all sizes correspond closely with those of the Iowan oxidized and leached till.

Oxidized and Unleached Mankato Till

The general appearance of the oxidized and unleached Mankato till is so similar to the oxidized and leached phase above that its differentiation is dependent upon tests with acid. The transition zone between the leached and unleached zones is indistinct and is

	Mankato Till Unleached	Mankato Till Leached
Greenstone	19.00	36.50
Greenstone Schist	1.00	2.00
Granite	21.00	40.00
Diorite	1.00	2.00
Syenite		
Porphyry	3.00	6.00
Other Crystallines	3.00	6.00
Quartzite	1.00	2.00
Quartz	1.00	2.00
Sandstone	1.00	2.00
Limestone	47.00	
Chert	1.00	2.00
Shale		
Clay Ironstone		
Hematite and Jasper		

Figure 78. Lithological analysis of leached and unleached Mankato till.

an irregular thin zone of downward penetrating fingers of till between blocks of unleached till which have the appearance of included masses in the base of the overlying phase.

In color, the oxidized and unleached till is light yellow to yellowish gray on a dry slope, yellow to brownish on fresh surfaces. It breaks readily into irregularly shaped fragments and is not compact.

The clastic texture of the Mankato oxidized and unleached till is so nearly identical to that of the clastic texture of the oxidized and unleached Iowan till that it is impossible to point out differences. The minimum size grade as shown by the average mechanical analyses of figure 6, page 34, is below 1/64 millimeter in diameter. Although it varies in different samples, the average is about 25 percent. The next coarser size grade, 1/32 to 1/64 millimeter in diameter, has an average of only 7 percent. In each of the separate samples, as well as the average, this was followed by an increase in percentage in the 1/16 to 1/32 millimeter size grade, a slight decrease in the 1/8 to 1/16 millimeter size grade, and another small increase in the 1/4 to 1/8 millimeter in diameter size grade. Above 1/8 millimeter in diameter there is no uniformity within the different samples.

The lithology of the oxidized and unleached till is almost identical with that of the oxidized and leached Mankato till except that it contains almost 50 percent limestone (fig. 78). The oxidized and unleached till has been altered from the original till only by the oxidation of some of the iron compounds. This oxidation involved practically no disruption or solution so the shapes of the grains of all sizes are unchanged and show no rounding by solution. Some of the pebbles show marks on the surface formed during transportation by the ice.

Unoxidized and Unleached Mankato Till

The basal phase of Mankato till, the unoxidized and unleached zone, is rarely seen due to the scarcity of deep cuts in the Mankato drift plain where the drift has a greater depth than has been penetrated by oxidation processes. As in the transition zone between the two phases above, the change from oxidized to unoxidized till is irregular, appearing as interfingering zones, more or less determined as to position by the major jointing of the till.

The color of the unoxidized and unleached Mankato till is dark gray except along the joint lines, which are lined in yellow from incipient oxidation. The unoxidized till is highly calcareous and breaks into irregularly shaped fragments. Occasional inclusions of sand are oxidized.

The unoxidized and unleached Mankato till has an average clastic texture almost identical to that of the unoxidized and unleached Iowan till. In no part of the analyses is there a difference of more than 4 percent within any one size grade; (fig. 6, p. 34). A comparison of the unoxidized and unleached with the oxidized and unleached Mankato till (fig. 6) shows that there is no evidence of weathering and disruption within the oxidized and unleached till which would result in an increase in the percentages of the finer size grades.

The lithology of the unoxidized and unleached till is the same as that of the oxidized and unleached till, which bears out the above statement that there has been no appreciable amount of weathering within the oxidized and unleached material, for the rocks of the unoxidized and unleached till have not been subjected to alteration and represent original material.

The shapes of the grains in the unoxidized and unleached till are the same as those in the oxidized and unleached till for neither has been altered by disruption or solution, but represents the shapes of the original material at the time of glacial deposition.

The Mankato Gravels

Gravels of two types are found related to the Mankato drift. As the ice sheet melted, masses of gravel were deposited within and on the till as irregular pockets and lenses, and as kame-like knobs on the till surface. This type of gravel is intimately associated with the till, being so related to till material as to preclude the deposition of the bodies of gravel apart from that of the till. The second type of Mankato gravel was deposited as outwash in the valleys in front of the ice margin, and may be found beyond the border of greatest extension of the ice sheet, or in the valleys on the Mankato drift surface which carried the glacial flow from the receding glacier. These two types of gravel have been studied and described by Kay and Miller.[122]

The Mankato Upland Gravel

The Mankato upland gravel is found predominantly in the morainic areas of the drift sheet. Most of the exposures occur in the morainic complex on both the east and west limits of the lobe, but are not common along the southern terminus where no distinct terminal moraine is evident. Deposits within the interior of the drift region are related to recessional morainic trends. The location of known upland gravel deposits is shown in figure 79. Reference to the Mankato morainic system, shown in figure 86 on page 239 of this report will demonstrate the relation of the upland gravel deposits to the topographic morainic features.

In general the gravels show wide variation in oxidation, cementation, structure and size range. The color of the gravel ranges from gray unoxidized gravel to the dark reddish-brown color of highly oxidized iron-cemented gravel. Some thin layers and seams are stained black by a coating of manganese dioxide on the grains. Cementation is not common, but in places iron oxide-cemented conglomerates are found. Gravels cemented by lime or manganese dioxide are rare. In structure, the gravel is very irregular, ranging from horizontal beds with well-marked lines of deposition to steeply dipping beds and prominent cross bedding. Clay-balls, lenses, pockets, and boulders are in many places in the usual horizontally bedded gravel. Some parts of exposures may show unstratified and poorly sorted gravel. The size range varies widely. Most of the gravel is smaller than 5 centimeters in diameter, but

[122]Kay, G. F., and Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, pp. 168-196, 1941.

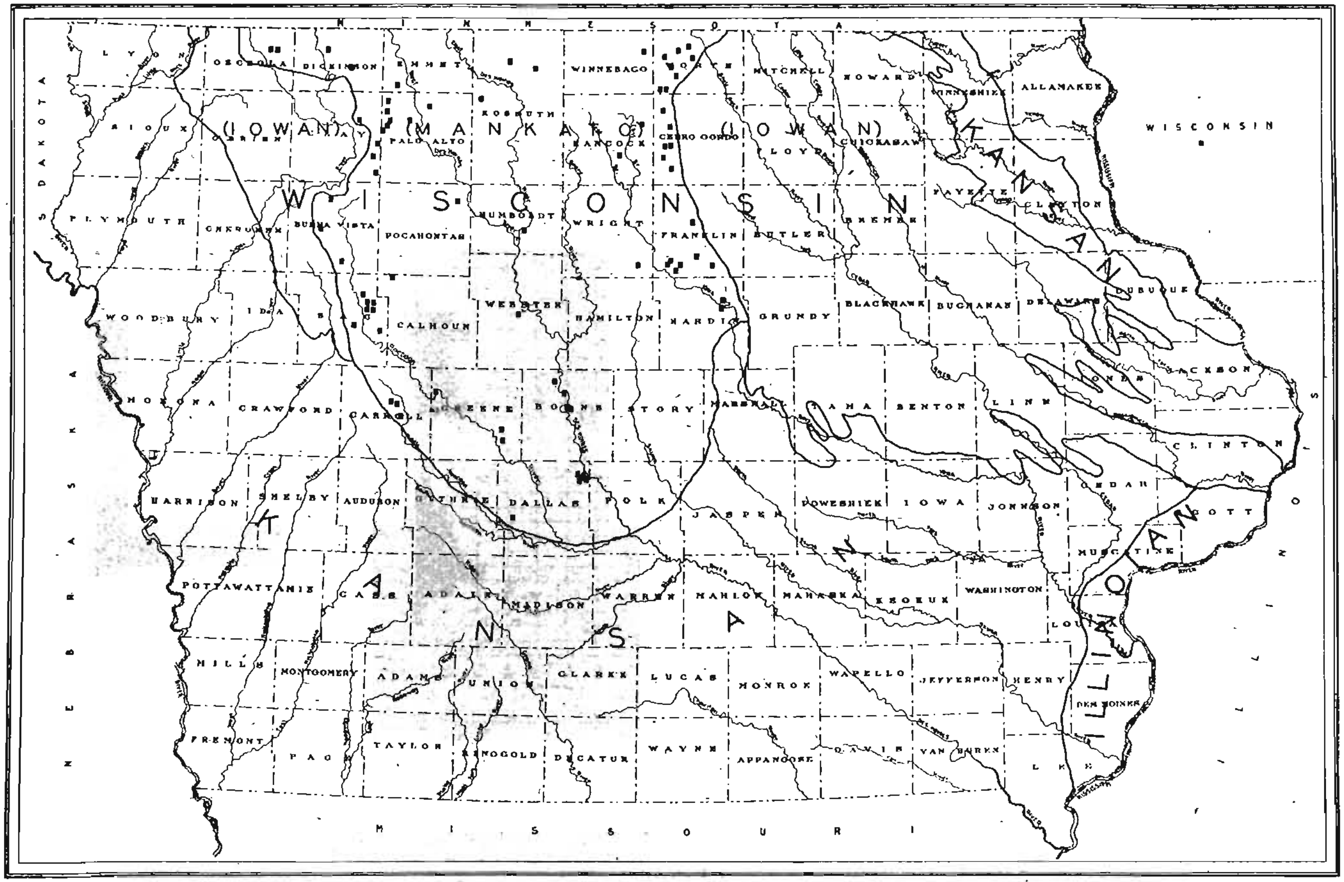


Figure 79 Map of Iowa showing locations of Mankato upland gravel deposits.

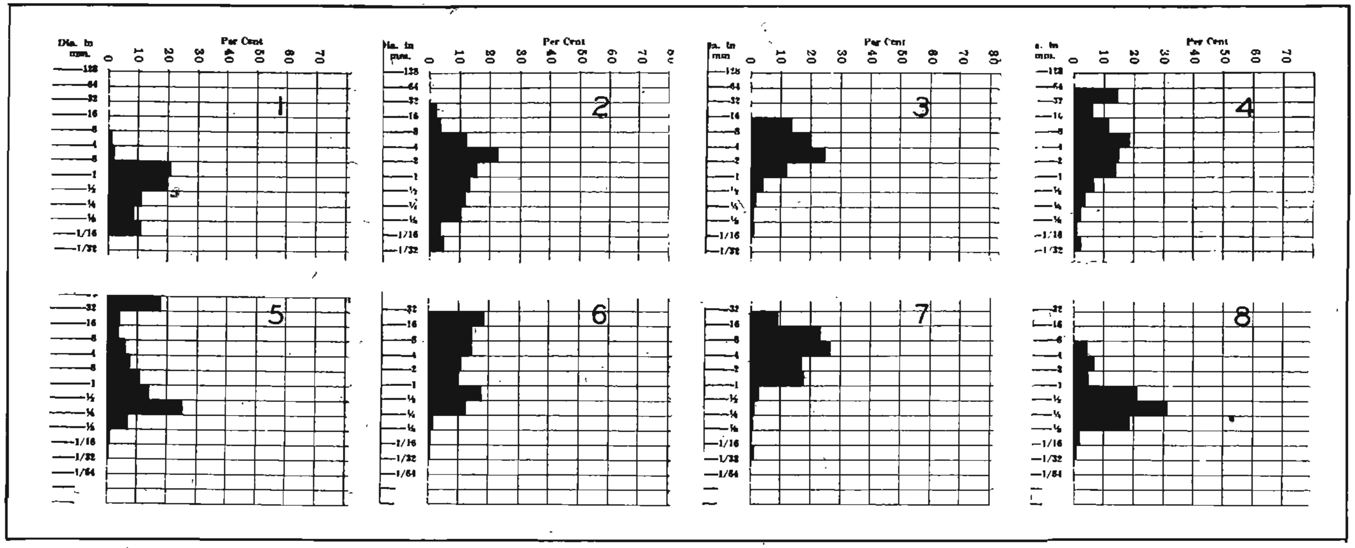


Figure 80. Graphs showing mechanical analyses of Mankato upland gravels.

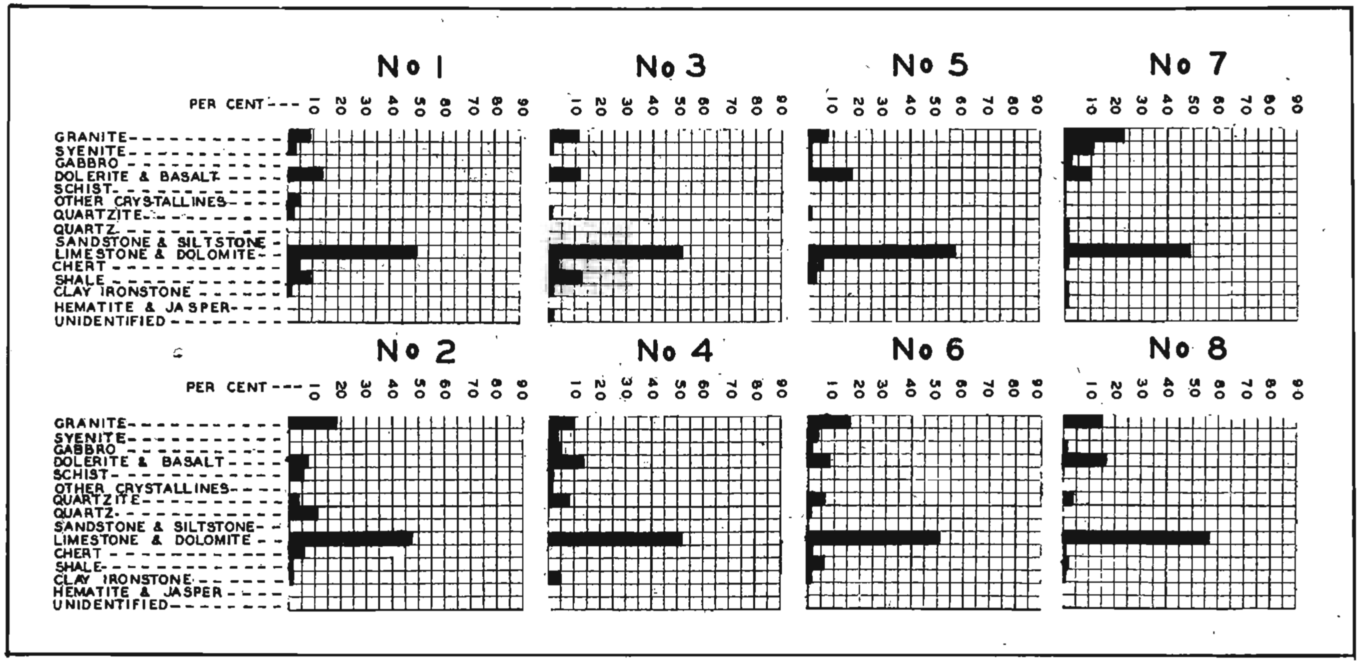


Figure 81. Graphs showing lithological analyses of Mankato upland gravels within the size range 16 to 32 millimeters in diameter.

cobbles and boulders as large as 75 centimeters in diameter are common. The percentage of each of the different size grades as found by a mechanical analysis of an average sample from each exposure is given in figure 80. Lithology of the pebbles between 16 and 32 millimeters in diameter of these same samples is shown in figure 81. The gravel cover is either Mankato till or a thin zone of loess-like silt. Leaching has affected the till materials to a depth of only 2 to 3 feet. Leaching and oxidation of the gravel is dependent upon the thickness of cover and conditions of erosion.

A typical Mankato upland gravel exposure is in the northeastern part of the drift sheet, in Worth County. It is a pit in the SW¼ sec. 27, Hartland Township, (T. 100 N., R. 21 W.), along the north side of State highway 105, west of Northwood. The gravel is a kame deposit on the Mankato till surface. This deposit is in the terminal moraine area and is one of many kames which characterize this area of the drift border. The contact at the base of the gravel was not exposed, although the pit extends down more than 4 feet below the general surface of the drift plain.

The gravel is gray and is unoxidized except for the thin gradational zone between the gravel and the thin silty overburden. Leaching has extended into the gravel only where the overburden is less than about 2½ feet thick. In one part of the pit where the overlying silt is 16 inches thick, leaching of the gravel has occurred to a depth of 1 foot. The general appearance of the gravel is fresh, though some of the coarse crystalline rocks have been disintegrated along the margins by weathering so that crumbling occurs. In size range the pit material varies from fairly fine, well stratified sand and gravel in the middle to coarser, poorly sorted material containing cobbles and boulders in the border areas of the deposit. Most of the gravel is less than 3 centimeters in diameter but cobbles and boulders range from 20 to 40 centimeters in diameter. Size grades and lithology of the constituent pebbles are shown in graph no. 1, in figures 80 and 81, respectively.

In the SE¼ SW¼ sec. 36, Hardin Township, (T. 89 N., R. 21 W.), Hardin County, about 6 miles southeast of Iowa Falls, 9 feet of Mankato upland gravel is exposed in a pit excavated in an irregular gravel mass enclosed in the Mankato till. Eighteen inches of pebbly, sandy silt covers the gravel deposit.

The gravel is gray, unoxidized except for the gravel-overburden gradational zone, and leached for about 1 foot below the overburden contact. The deposit is largely gravel finer than 2½ centimeters in diameter, and coarse sand. Cobbles and boulders are uncommon. Stratification is good and cross bedding and lensing of coarser gravel with sand is common. The mechanical analysis of an average sample from this exposure is shown in graph no. 3, figure 80. Mineralogical analysis of the size grade from 16 to 32 millimeters in diameter is given in graph no. 3, figure 76.

Many fine Mankato exposures are in the morainic areas along the northwest boundary of the drift sheet, principally among the knobs and kames of the Ruthven moraine which extends southward from Minnesota into Iowa along the western border of the Mankato drift. Such an exposure is near the town of Ruthven, near the center of the north line of sec. 21, Highland Township, (T. 96 N., R. 34 W.), Palo Alto County. This exposure is in the morainal region but is on the flat upland.

The material is largely sand and fine gravel, boulders being rare and found only in the base of the pit. The section of this exposure is as follows:

	Feet	Inches
Mankato glacial substage:		
Overburden; loess-like silt containing only an occasional pebble; leached, colored chocolate brown by iron oxide and humus, unstratified; grades into similar material containing a much greater percentage of pebbles, and lighter brown color from oxidation alone	2	3
Gravel: light brown, leached only in the upper part; consists of interbedding of sand and fine gravel. Gravel beds are generally 1 to 2 inches thick and sand beds about 6 inches thick; neither is of uniform thickness over any horizontal distance and they often represent large thin lenses. Cross bedding dipping toward the southwest is present in the sand	5	
Gravel: interbedding of coarse and fine material. The coarse material is almost all smaller than 5 centimeters in diameter and only a low percentage is larger than 2 centimeters in diameter; beds of coarse gravel are about 5 inches thick, fairly continuous throughout the exposure horizontal but slightly wavy, Some lens-and-pocket structures; cross bedding is distinct within the finer gravel and sand beds	6	
Sandy silt: bed 6 to 10 inches thick, generally continuous but lenses out along the margins; contains no coarse material; beautifully stratified with a fine delicate structure consisting essentially of cross bedding, lens-and-pocket structures		10
Gravel and sand: chiefly sand, including fine stringers of fine gravel; structure essentially cross bedding, lenses, and pockets which dip generally toward the southwest. In the upper 1 foot of this zone the material is chiefly in horizontal beds within which are few irregularities such as cross bedding, lens-and-		

pocket structures. Interbedded with this are beds of finer gray sand, sometimes colored dark brown by iron oxide. The coloration is parallel to the stratification	6
Gravel: coarser than the rest of the exposure; upper and lower 3-foot members are medium coarse gravel while the middle 1-foot member is coarse. Stratification is poor, especially in the middle member. Some material is as large as 20 centimeters in diameter and much of it larger than 8 centimeters in diameter	7

The mechanical analysis of gravel from this section is shown in graph no. 4, figure 80, with the rock analysis given in the corresponding graph in figure 81.

The sections given above are typical of the upland gravels found in and on the Mankato till. The syngenetic relation of such gravels to the till is displayed in numerous sections. These sections show that the upland gravels may be found as "irregular masses which may be either deep within or near the surface of the till, as kame-like hills or esker-like ridges on the surface of the till, as irregular masses included within till of kame-like hills, and as lenses and thin beds interbedded with till."

Mankato Terrace Gravel

Kay and Miller,[123] in discussing the Mankato terrace gravel have described only those deposits lying within the borders of the Mankato drift sheet, for while it is possible to differentiate the Mankato gravels from others where their relation to other known materials is definite, the interphasing of gravels of Loveland, Iowan and Mankato age beyond the Mankato drift borders presents a problem in gravel differentiation beyond practical value of solution, and they have been grouped together as "undifferentiated terrace gravels" and will not be discussed here as a definite phase of Mankato materials.

Within the drift borders, Mankato terrace gravel is found in the valley of almost every stream in the region, often filling the stream valleys and forming the present walls of the streams which are now intrenching themselves and forming terraces of the gravel which was deposited by vigorous streams issuing from the retreating Wisconsin glacier.

These glacial valleys may have been pre-Mankato valleys which were not obliterated by Mankato drift and still served as drainage-

[123]Kay, G. F., and Miller, P. T., The Pleistocene gravels of Iowa: Iowa Geol. Survey, vol. 37, p. 180, 1941.

ways. Others appear to be consequent streams which developed on the uneven surface of the new drift surface. The distribution of the exposed Mankato terrace deposits within the area of the Mankato drift is shown in figure 82.

The gravel forms terraces along most of the streams, ranging in height from flood plain level to as much as 120 feet above present stream level. Most of the terraces, however, are between 25 and 35 feet above the stream.

The overburden is sandy to loess-like silt which may or may not contain pebbles. This silt cover may be entirely absent or range to a thickness of 6 feet, but in most places is usually quite thin, so that the gravel cover and the upper several inches of the gravel is usually leached of the carbonate content, though the total depth of leaching is rarely more than 3 to 4 feet. There is generally a gradational zone between the gravel and overburden in which intermixing has occurred. This zone frequently shows more marked oxidation than the silt above or gravel below.

The gravel is highly calcareous except where leached to a shallow depth at the top. Concretions of secondary calcium carbonate are found below the leached zone in some exposures and occasionally cementation occurs. In color the gravel ranges from rusty brown to gray, most deposits being gray to grayish buff. As in the upland gravel, a few of the igneous rocks such as granites, greenstones and schists, are weathered and crumble under slight pressure. The structure is fairly uniform throughout most of the exposures. Stratification is mostly gently dipping with abundant cross bedding. Most of the gravel is finer than 32 millimeters in diameter, although cobbles are encountered which range up to 20 centimeters in diameter. Figure 83 gives the size percentages of several typical exposures. In northeastern Iowa, much of the coarse constituency of the finer well-stratified gravel consists of limestone plates which usually lie with their greatest diameters parallel to the bedding. Mineralogical analyses of samples of the terrace gravel are given in figure 84.

A representative exposure of Mankato terrace gravel is found in a large gravel pit along the south side of the Iowa River near the southeast corner of Iowa Falls, in the NE¼ sec. 19, Hardin Township, (T. 89 N., R. 20 W.), Hardin County. The terrace level is 50 to 55 feet above the river. The gravel is exposed to a depth ranging from 13 to 18 feet.

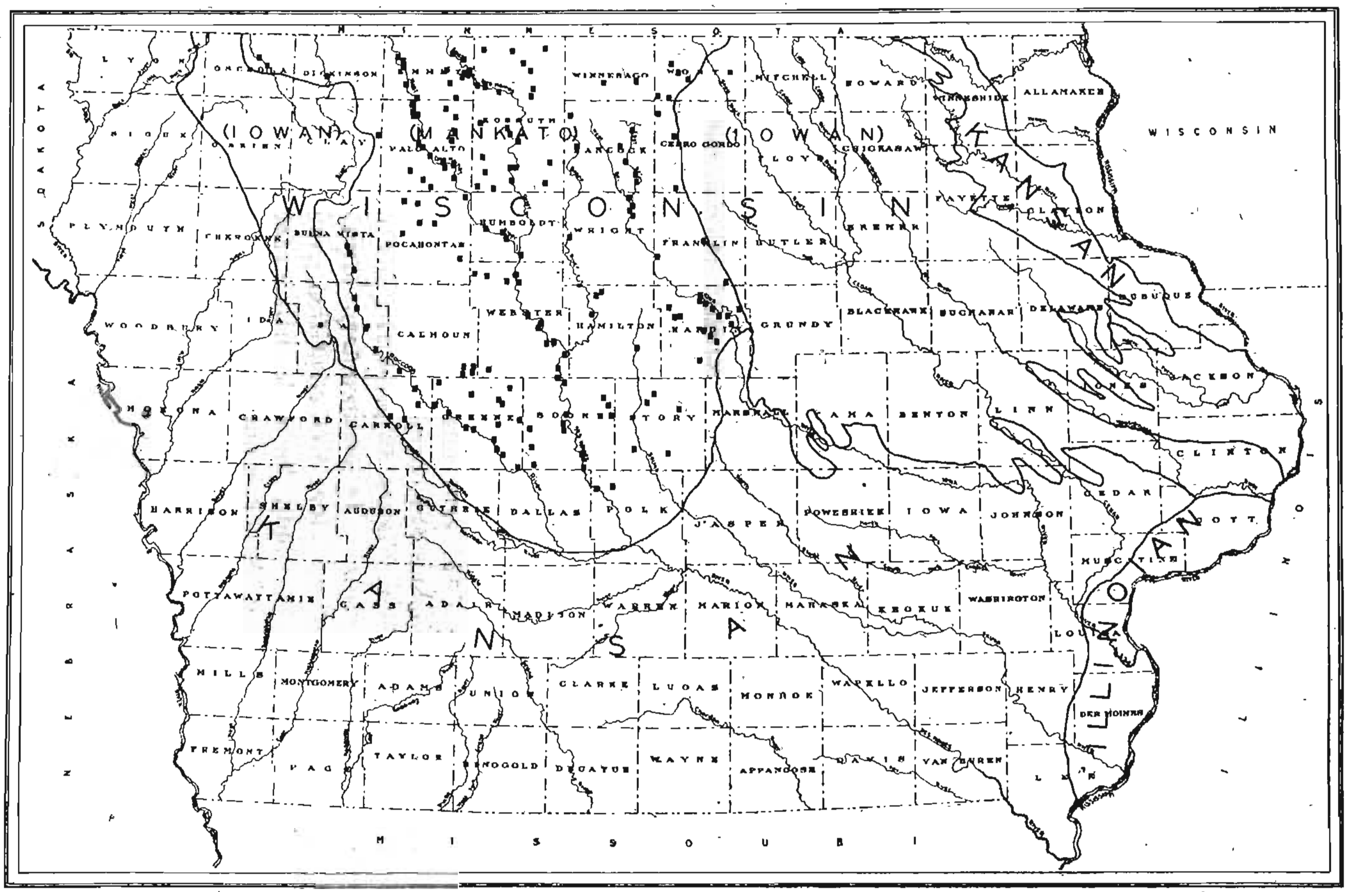


Figure 82. Map of Iowa showing locations of Mankato terrace gravel deposits.

The gravel is very slightly oxidized and such buff color as is apparent is due to original color in the limestone and dolomite fragments. Leaching is normally found to a depth of about 30 inches, for the most part in the overburden; but where this is thin, it may extend into the underlying gravel. No disintegration of the igneous rock material is found. The limestone and dolomite content reaches as much as 60 per cent in one end of the pit, in which the platey fragments are imbedded in a matrix of much finer calcareous gravel. These plates lie characteristically with their long dimension parallel to the poor stratification of the finer gravel. For the most part the gravel in this exposure is well sorted, 85 percent of the average gravel is between the size grades of 1/2 and 8 millimeters in diameter. The mechanical and lithological analyses of this gravel are shown as nos. 1 of figures 83 and 84.

From a pit operated by the Chicago, Rock Island and Pacific Railway, Mankato terrace gravels have been reported to have been removed to a depth of 45 feet. At present 20 feet of the gravel is exposed above the water in the pit.

The exposure occurs along the Des Moines River north of Graettinger, extending from the south central part of sec. 29 to the center of sec. 32, High Lake Township, (T. 98 N., R. 33 W.), Emmet County. The silty overburden is pebbly, especially at the base of the 4-foot average thickness. The gradational zone between overburden and gravel is thin. Leaching has removed the carbonates to a depth of 2 feet. Limestone pebbles occur below this depth in the overburden, and the gravel is composed of about 50 percent of carbonates. Hence, the gravel is light colored, a light buff gray. A few lenses and thin beds are more deeply stained by iron oxide. Stratification is marked, the beds averaging about 2 feet thick and dipping slightly to the southwest. Cross bedding and lens-and-pocket structures occur within beds of finer material. In size, the gravel is mostly smaller than 3 centimeters in diameter. Boulders are rare. The size grade percentages and the pebble lithology are given as nos. 5 in figures 83 and 84, respectively.

An example of Mankato terrace gravel in the Raccoon River Valley is found near the center of sec. 13, Jackson Township, (T. 83 N., R. 31 W.), Greene County, about one-half mile from the southwest corner of Jefferson. Here 13 feet of gravel is exposed in a terrace 20 feet above the level of the river.

The irregular surface of the gravel is covered by 2 to 4 feet

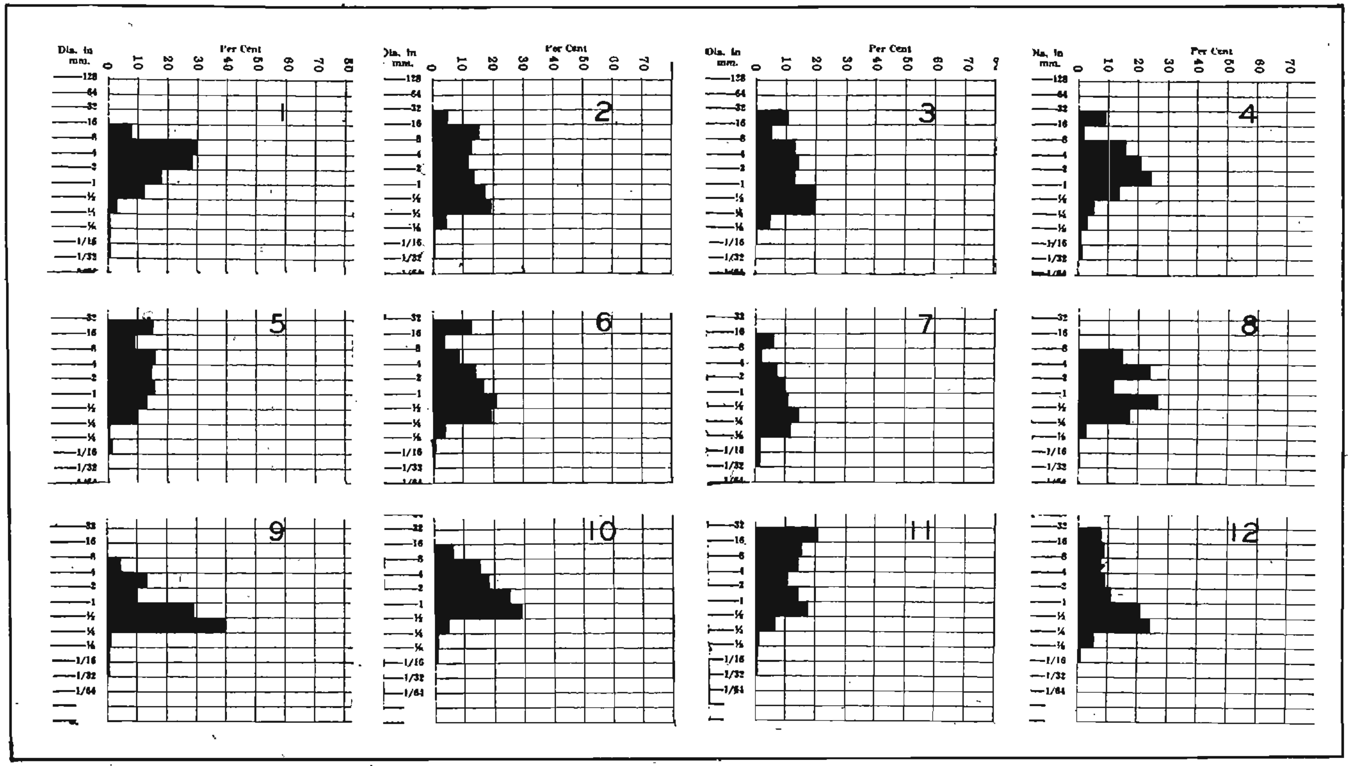


Figure 83. Graphs showing mechanical analyses of Mankato terrace gravels.

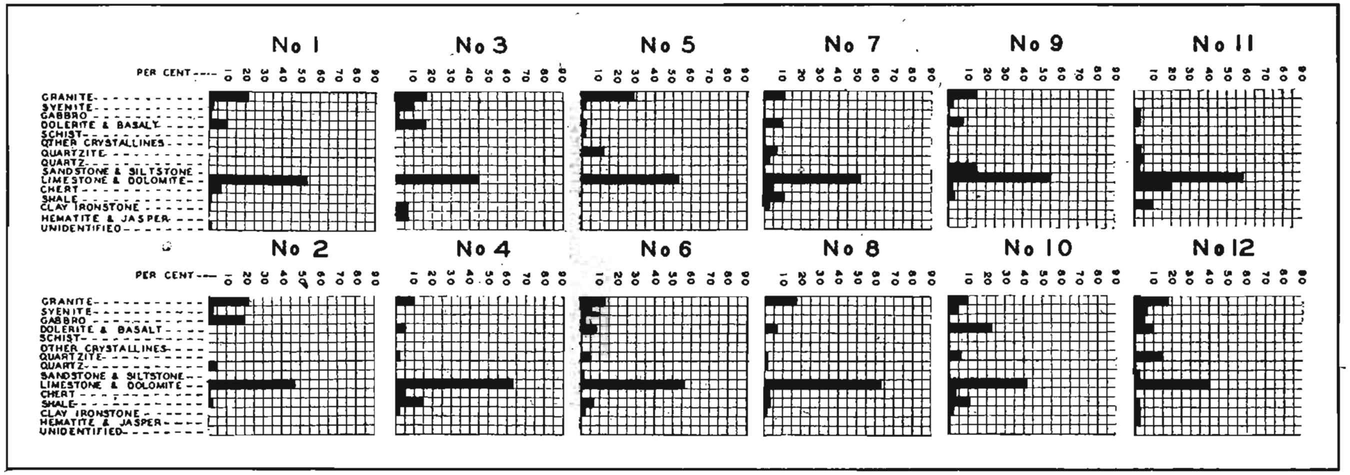


Figure 84. Graphs showing lithological analyses of Mankato terrace gravels within the size range 16 to 32 millimeters in diameter.

of overburden. Leaching in the thicker overburden has penetrated downward 40 inches. Where the gravel cover is about 2 feet, the upper few inches of the gravel is leached. The color of the deposit lightens downward. The leached overburden is chocolate brown from humus and oxidation. The unleached overburden is light brown and contains some limestone pebbles. A layer of 1 to 4 feet of coarse gravel just below the overburden is a light rusty brown below which the main body of gravel shows less oxidation and is a light grayish buff. The deposit is poorly stratified, with some beds about 30 inches thick which dip at a low angle to the north. Cross bedding is abundant in some of the horizons, the angle of dip being about 40 degrees in various directions. In size, most of the gravel is finer than 3 centimeters in diameter and nothing larger than 10 centimeters in diameter was observed. The diagrammatic representation of the size grades is shown as no. 6 in figure 83. The lithologic percentages are given in no. 6 of figure 84. Due to the quick disintegration of the shale content upon exposure to agencies of weathering, the shale does not appear in the above pebble analysis in its true proportions. Besides the shale, some of the granites and schists in the upper layer of coarse gravel are weathered.

Many other exposures of Mankato terrace gravel similar to those given above have been examined and studied. The valleys in which they occur may have been formed in the Buchanan interval and partially filled but not destroyed by Iowan and Mankato drift, leaving shallow linear sags which became the drainageways for the meltwater of the retreating Mankato glacier. Other terraces are found in valleys which do not indicate a history prior to Mankato glaciation and hence were developed by consequent streams uninfluenced by previous drainage lines. Within the Mankato drift, the identity of the gravel making up the terraces in the drift valleys is without question Mankato in age, but beyond the drift borders such gravel can be distinguished only by its relation to known till and loess deposits. Some exposures show the gravel in superposition with Peorian loess, and this can be determined as Mankato gravel with assurance. But in many cases, the relation of the gravel to underlying deposits is not visible, and while topographically it may be inferred that the terrace is an extension of levels existing on the Mankato drift, the gravels in themselves are not distinct from older terrace gravels and are thus classified as undifferentiated terrace gravels.

The Mankato Morainic Complex

The surface of the Mankato drift is generally a flat or slightly undulating plain except for a more or less well-developed constructional morainic topography consisting of low-lying mound-like hills and depressions on the ground moraine surface, as shown in figure 85. As a whole, the knobby, kame and kettle topography characteristic of fresh terminal and recessional moraines is not pronounced in the Mankato area, and ridge-like morainal deposits existing as prominent features on an otherwise flat and low plain are not always apparent. Two main morainic systems, however, are fairly distinct and have long been recognized by geologists and soil men familiar with this region.

Figure 85. Mankato morainic topography; Wright County.

White,[124] as early as 1870, correctly interpreted some of the more prominent morainic features of the area. He describes two of the most noticeable morainic features in the following manner:

"They (the moraines) seem at least to be accumulations of drift material which mark periodical arrests of the recedence by melting, of the glaciers to the northward as the Glacial epoch was drawing to a close, as a consequence of a gradual change of climate. They consist of two well-marked but

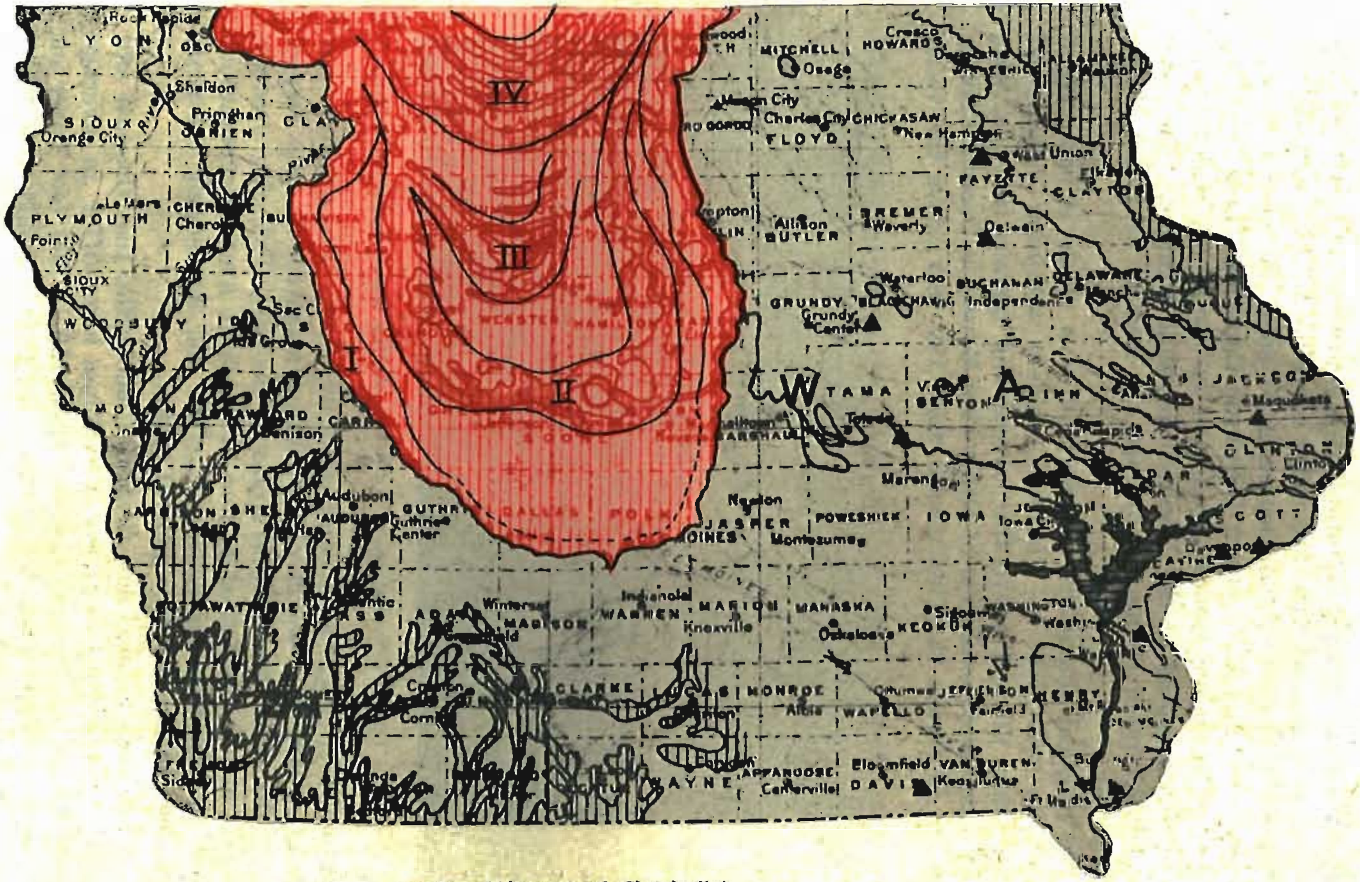
[124]White, C. A., The geology of Iowa, report on the geological survey of Iowa: vol. 1, pp. 98-99, 1870.

slight elevations in the general surface of the country. They both have an easterly and westerly direction, and are gradually lost at either end in the general prairie surface. One of them extends through the northern part of Boone and Story counties, and is known to the inhabitants as 'Mineral Ridge.' It consists to a considerable extent of a collection of slightly raised ridges and knolls, sometimes interspersed with small, shallow ponds; the whole having an elevation probably nowhere exceeding fifty feet above the general surface, but being in an open prairie region it attracts attention at considerable distance. It is composed wholly of drift.

"The other ridge extends from the eastern part of Palo Alto county through Kossuth into Hancock. The greater part of this ridge has the general, but indistinct character of a terrace, facing the south, and elevated only from fifteen to twenty or thirty feet above the general level of the surface to the southward, while the general level to the northward stretches away from the top of it. It is nowhere very distinctly marked even in so flat a region as this, but yet it is sufficiently so to have caused its existence to become generally recognized by the inhabitants. Its eastward extension into Hancock county becomes broken up into a well-marked strip of 'knobby country.' Here it consists of elevated knobs and short ridges wholly composed of drift, and usually containing more than an average proportion of gravel and boulders. Interpressed among these knobs and ridges are many of the peat marshes of that region."

More detailed work was done by Chamberlin,[125] who in 1878 noted a distinct moraine along the western limb of the Des Moines ice lobe. Chamberlin, with Upham, determined the terminal moraine to consist essentially of a double morainic line extending from a point a few miles south of Minneapolis southward into Iowa as far as Polk County, then doubling back to the north and west to the southern Minnesota line, from there following the northeastern slope of the Coteau des Prairies to its head in South Dakota to the west of Lake Traverse. In Iowa, the trend was described as extending diagonally across western Worth and southeastern Winnebago, western Cerro Gordo and eastern Hancock, Franklin, Hardin, Story and Polk Counties, crossing the Des Moines River a short distance below the capital city. From there it stretches northwesterly along the Middle Racoon River, diagonally through northeastern Guthrie and central Carroll into Sac County, then northerly in Buena Vista County, to the east through eastern Clay, and westward again through central Dickinson and northeastern Osceola Counties. This description is essentially that of the outermost moraine as mapped by Iowa geologists today. Upham and Chamberlin described the inner morainic line as running from Hancock County south through eastern Wright and Hamilton Counties where it curves to the west to include Mineral Ridge, which had been described earlier as a moraine by White. From Mineral Ridge the moraine continues across north-

[125] Chamberlin, T. C., Preliminary paper on the terminal moraine of the second glacial epoch: U. S. Geol. Survey, 3d. Ann. Rept., pp. 388-393, 1881-1882.



I. Bemis moraine (Altamont of Chamberlin)
II. Altamont moraine (Gary of Chamberlin)
III. Humboldt moraine
IV. Algona moraine

Figure 86. Glacial map of Iowa with the major Mankato moraines indicated by number.

ern Boone and Greene Counties, thence north to Palo Alto County where it coalesces with the outer moraine at the easterly re-entrant of the latter, but separates to enter Minnesota through western Emmet and eastern Dickinson Counties. These two main terminal morainic trends are shown in figure 86, which shows a recent mapping of the Mankato morainic complex. The outer and inner main terminal moraines are marked as I and II, respectively.

In physical character, the moraine as a whole is less rugged than its equivalent in Wisconsin, seldom attaining heights of more than 50 feet above the surrounding terrain in Iowa, with the pronounced exception of Ocheyedan Mound in Osceola County, shown in figure 87. This mound rises 150 feet above the valley

Figure 87. View of Ocheyedan Mound, a Mankato morainic feature in Osceola County.

bottoms and covers an area of about 40 acres. The morainic material is largely a clayey till, differing markedly in this respect from the rocky moraines of areas to the east. This clay predominance may be explained as due to the large areas of Cretaceous shale constituting the bedrock surface and influencing the drift lithology throughout this general region.

It has been pointed out, first by Chamberlin, that the east and west morainal borders of the Des Moines lobe differ in average elevation by an amount ranging from 150 to 200 feet lower on the east than the west. Whether the ice tongue would have taken its observed direction rather than following the dip of the surface to the east, had this entire elevational difference existed in Mankato time, is not known, but it is considered unlikely. However, there is little topographic evidence either in western or eastern Iowa which can be presented to substantiate a relative shift in elevation of as much as 150 feet, though western Iowa is thought to have received a relative elevation over eastern Iowa of unknown proportions in the post-Kansan pre-Iowan interval.

In the report by Chamberlin[126] cited above, the name Altamont moraine was given to the moraine which to that author seemed to be the outer terminal moraine of the lobe in its continuation in the Iowa part of the drift. The name was taken from the town of the same name situated on a prominent morainal elevation in the eastern part of South Dakota. An inner moraine not far to the east of Altamont, South Dakota, passes through Gary and vicinity, a town situated on the South Dakota-Minnesota state line, and from this locality the name Gary has been taken for the moraine which parallels the Altamont moraine on the east, and which was thought to be manifest in Iowa as the inner moraine including Mineral Ridge. These two morainic belts are separated in the region of the type localities by a distance of 5 to 6 miles of gently undulating drift plain. There is little difference in the massiveness, breadth, height, complexity or constitution of the Altamont and Gary moraines, as identified by Chamberlin. Still to the east of the two prominent ridges, a third and more feeble morainic trend, locally known as Antelope Hills, lies at a distance of 12 to 15 miles east of the Gary moraine and roughly parallel to the outer two.

This terminology for the Des Moines lobe terminal moraines was used as originally described until Leverett[127] in 1922 published the results of field investigations by Lees and himself in which the use of the name Altamont for the outer moraine of the lobe is questioned. According to Leverett, there exists a moraine a short distance to the west of the type locality of the Altamont moraine, passing through the town of Bemis, South Dakota. This moraine parallels but is distinct from the Altamont moraine and is traceable southward as the true outer moraine, the Altamont moraine in actuality being the inner moraine in Iowa. Leverett

[126]Chamberlin, T. C., *op. cit.*, p. 393, map, pp. 382-383.
[127]Leverett, Frank, What constitutes the Altamont moraine: (Abstract) Geol. Soc. America Bull., vol. 33, pp. 102-103, 1922.

gave the name Bemis to the outer moraine and suggested the continued use of the name Altamont for the moraine passing through the town of that name but now considered to be the inner rather than the outer terminal moraine in Iowa. This usage is adopted in the present report and has been applied to the map shown in figure 86.

In a report on fertilizer materials of Iowa, published by J. E. Smith[128] in the reports of the Geological Survey of Iowa, a map of the Des Moines lobe morainic system is given in which Chamberlin's original application of the name Gary for the inner moraine is used, and two prominent recessional stages of the melting glacier are mapped, termed the Humboldt and Algona stages in respective order inward. These are shown as moraines III and IV in figure 86.

The question as to the approximate contemporaneity of these various moraines of the Des Moines lobe has never become an issue due to the obvious array of evidence pointing to normal stages in the advance and recession of a single glacial mass. In morainal characters as to material, topography, position, and reduction by erosion; in appearance, and relation of outwash materials to drainage features; in degree of surface till modification by weathering of the various areas of the lobe; and in physiographic age of the various areas of the lobe, the similarities are so striking and the unity of the effects of glaciation so apparent, that glacial geologists have in general accepted the single glacier view of the Mankato drift in Iowa and its morainic complex.

Thickness of the Mankato Drift

Reference has already been made to the fact that few highway or railroad cuts of any great depth are to be found within the strikingly level area of the Mankato drift. Consequently, with the exception of a few exposures near the drift borders, good sections of the till showing the entire depth are rare. Yet a study of such sections as are available, aided somewhat by well logs, indicates an average depth of about 30 to 35 feet for the Mankato till, though considerable variation in thickness is found. Thus, in Greene County, a fine section in the N½ sec. 27, Grant Township, (T. 83 N., R. 30 W.), shows a thickness of 44 feet of Mankato till overlying from 6 to 20 feet of Peorian loess. In contrast, many sec-

[128]Smith, J. E., The fertilizer materials of Iowa: Iowa Geol. Survey, vol. 31, opp. p. 102, 1923-1924.

tions show a depth of but 5 to 10 feet of Mankato till, a thickness which is more characteristic of the veneer-like Iowan than the generally constructional Mankato.

But the Mankato, as the Iowan drift, is not of sufficient thickness to have become completely distinct in its topography. Some of the drainage lines on the Mankato surface were inherited, not only from the Iowan surface, but through it from the eroded topography of the Kansan plain. Yet the general features of the hummocky plains of north-central Iowa have been thought to be entirely Mankato in origin and the region as a whole displays a drift depositional topography.

A somewhat different view of the morainal features of the Mankato drift—a view which implies a relatively thin drift sheet—has been presented by C. S. Gwynne,[129] who suggests that the mappable morainic features in the Mankato area are Iowan moraines which find surface expression through a thin and essentially moraine-less Mankato drift. This argument is based upon a study of aerial photographs which seem to indicate trends of the Mankato ice margins with no apparent relation to the much larger morainic features which have been mapped by field surveys.

[129]Gwynne, C. S., Swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in Iowa: Jour. Geology, vol. 50, pp. 200-209, 1942.

CHAPTER IV.

THE ELDORAN EPOCH (SERIES)
THE RECENT INTERGLACIAL AGE (STAGE)

The record of the Recent
Descriptions of Recent features
 Leached Mankato drift
 Peat on the Mankato drift
Duration of the Recent

The term Recent was used first by Charles Lyell[130] for the period during which the earth has been inhabited by man. This original use would include the Recent and Pleistocene of the present classification. Following Forbes' re-definition of the term Pleistocene in 1846, the term Recent came to mean "post-glacial," and has carried that meaning down to the present time.

The Recent, by most geologists, has not long been considered a part of the Pleistocene, or Glacial period. Rather, it has been largely left as the domain of other fields of science, and until recently, much of what was known about geological conditions since the retreat of the last continental glaciers from North America came through interest in anthropological, archeological, and biological problems. Within the past few years, however, geologists have turned to sedimentational studies of existing late Glacial lakes, to tree rings, to cores taken from ocean bottoms, to cave deposits, and to soil zones in Wisconsin and Recent loesses, and progress is slowly but surely being made in exposing the conditions of the recovery, or partial recovery of North America from Wisconsin glaciation.

The place of the Present in relation to glacial and interglacial conditions can never be completely known by contemporary science for such obviously presumes knowledge of the future. However, most glacial geologists are of the opinion that the Present is not dissimilar from conditions which probably prevailed in the recovery phases of earlier interglacial ages. That the Present is not far advanced in point of time from glacial conditions, is evident from studies of existing but waning continental ice sheets in Greenland and Antarctica. It may be properly said that in those regions the Recent interglacial age is yet to come.

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[130]Lyell, Charles, Principles of Geology, vol. 3, pp. 52-53, 1833.

Kay and Leighton,[131] in proposing to include the Recent in the Pleistocene, state:

"During the Recent age the Mankato (Late Wisconsin) drift on uneroded uplands has been leached of calcium carbonate to a depth of about 30 inches. The time involved is considered to have been approximately 25,000 years. Since there is no evidence that the Recent may not be the beginning of another interglacial age, it would seem to be logical to regard the Recent as a part of the Pleistocene, or Glacial, period."

THE RECORD OF THE RECENT

The Recent, as interpreted in Iowa, includes that interval of time beginning with the disappearance of the late Wisconsin, or Mankato, ice sheet, and extending to the present. It is perhaps needless to add that this concept of the Recent in relation to the Pleistocene of Iowa will not be the exact time equivalent of the Recent in other regions.

All materials which have been deposited subsequent to the deposition of the Mankato drift in Iowa are Recent deposits, and also, all changes which have affected the Mankato drift or materials of later deposition, are changes which occurred in the Recent age. It follows, therefore, that deposits and changes in Iowa belonging to the Recent must be related to the Mankato drift to carry proof of belonging to the Recent. An exception—which is used by students of human pre-history—would be deposits anywhere which can be shown to contain Recent life forms, such as Indian remains.

Within Iowa, the most important factors in the study of the Recent record are the changes to be seen in Mankato deposits. Oxidation and leaching of the calcium carbonate have occurred and these changes serve as the best approach to the relative duration of the Recent. The stage of erosion serves as a useful tool of comparison. Recent deposits are relatively unimportant, for the reason that with the exception of peat, no post-Mankato materials have been recognized on the Des Moines lobe, and because few deposits beyond the Mankato borders can be delimited as post-Wisconsin.

Elsewhere, good use has been made of human cultural levels, Recent soil zones, lake bottom accumulations, etc., but these criteria have not been applicable in Iowa because of the scarcity of such deposits.

[131] Kay, G. F., and Leighton, M. M., The Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, p. 673, 1933.

DESCRIPTIONS OF RECENT FEATURES

Leached Mankato Drift

The three oldest drifts in Iowa, namely the Nebraskan, Kansan and Illinoian, were in each case exposed to weathering agencies for a sufficient length of time to allow a widespread development of gumbotil, mesotil or silttil wherever the drift plain was not being reduced by erosion. The Iowan substage of the Wisconsin stage does not have a gumbotil development but is leached of its calcium carbonate to an average depth of 5½ feet. The Mankato substage exhibits the least change of all. There is no gumbotil development, and the depth of leaching is but 2½ feet on the average—less than one-half that of the Iowan. Figure 28, page 108, illustrates the depth of leaching at numerous sections in both the Iowan and Mankato drift areas.

There can be little doubt that there is a close relationship between the time during which weathering agencies of interglacial ages acted on glacial materials and the depth of the resulting chemical changes. In the case of the Mankato drift the only determinable results have been the slight leaching of about 30 inches, and a variable amount of oxidation which in most places extends to a depth of less than 10 feet.

This lack of any pronounced change in the original drift material is an indication of extreme youth, and is in complete accord with other criteria of age. The stage of erosion, the poorly developed drainage pattern, the lack of mappable loess on the till, and the unreduced forms of the various constructional drift features all substantiate the interpretation put on the amount of leaching—that in a geological sense, the Recent has been extremely short.

Peat on the Mankato Drift

Immediately upon the withdrawal of the Mankato ice from north-central Iowa, such plant life as was suited to the cool and wet conditions of the barren expanse of fresh till began to spread over the drift surface. Mosses, sedges and grasses, and more infrequently shrubs and trees soon brought verdure back to the region. Marsh and swamp plants became established around the pond and lake borders and aquatic plants grew outward into the open water in matted masses. The poor development of drainage systems, the probable abundance of water and the climatic factors suitable for rapid and abundant growth of many types of land and fresh water plant life all indicate that conditions necessary for the widespread formation of peat were present.

Peat may be defined in a non-technical sense as partially decayed plant debris, the normal process of complete oxidation being arrested by a covering of water. Peat is ordinarily found as a fibrous, matted mass of brown to black plant material, but may in places be a non-fibrous, structureless muck or mud in which the plant debris has been changed almost beyond recognition as organic structures. It normally is very high in water content, ranging from 75 to 90 percent when first cut, and when air-dried may retain from 10 to 25 percent of water. Fibrous peats have a higher water content than that which is less fibrous. Fresh water shells are frequently found in the peat.

Peat may form in bogs, swamps or marshes, generally in depressions but in places on gentle hillsides at the site of seeps and springs. It may develop from almost a single type, or more often from a heterogenous group of plant forms including shrubs and trees, but Iowa Recent peats in the Mankato drift region have been found to consist primarily of grasses and sedges with mosses of secondary importance. Shrubs and trees are rare.

Most of the peat bogs of importance in the state are found within the borders of the Mankato drift, although small bogs are known to exist among the sand dunes formed in Wisconsin time and in Recent time along some of the main drainage systems of the state. The peat deposits of the Mankato drift are concentrated along the principal morainal belt on the east side of the lobe. They vary greatly in area and depth. They range in areal extent up to 1,500 acres and in depth to more than 35 feet. The deepest bogs are found in the rough knob and kettle topography of morainal areas, while the shallow peat deposits, which usually contain a poorer quality of peat than the deeper ones, occur in the more gentle depressions on the open drift plain.

A thorough study of the peat deposits of the Des Moines lobe was made by the Iowa Geological Survey, and a complete report of locations, thickness, and laboratory analyses of many samples was prepared by S. W. Beyer.[132] Figure 88 shows the location of the peat deposits in the Mankato drift area which were considered by Beyer to be large enough to present commercial possibilities.

[132]Beyer, S. W., Peat and peat deposits in Iowa: Iowa Geol. Survey, vol. 19, pp. 693-730, 1909.

Many of the locations on the map represent several deposits in conjunction.

Pollen profiles in buried peats in Iowa have been discussed earlier in the report. Application in America of pollen profiles in post-glacial peats has been gaining prominence following a much greater use of this method in Europe. Investigation of Recent peats has demonstrated the use of pollen profiles in archeological correlation; in climatic interpretations; and to some extent in estimates of Recent time.[133]

DURATION OF THE RECENT

Of even greater general interest than the span of time covered by the ice age as a whole is the length of time since Iowa was last buried under hundreds of feet of ice. This interest is strengthened by the fact that the human species probably inhabited North America during or just after the existence of the last continental ice sheet, and by the proved co-existence with man of several types of animal life of enormous size, now extinct.

Two lines of argument may be followed: (1) that man in North America is much older than formerly believed and has had considerable history on this continent, or (2) the time since glacial conditions prevailed in northern areas of the continent has been relatively short, and the presence of man in association with now extinct animals, and perhaps associated with deposits of glacial age, merely indicates the shortness of time since glacial conditions existed. The answer to this problem, and to the problem of yet more definite figures for the duration of the Pleistocene period as a whole, will be answered as the geological events of the Recent are gradually solved.

The effects of chemical and physical processes working on surficial Mankato materials have been discussed already in detail. Calcium carbonate has been leached from the upper 30 inches of till, on the average. Oxidation has proceeded to greater depths. The most constant process, that of leaching, affords a means of comparing post-Mankato time with time intervals during which older drifts were exposed to atmospheric agencies. This method of comparing the duration of the various drifts to weathering by the use of depths of leaching in their exposed gravels is explained

[133]Sears, P. B., Pollen analysis as an aid in dating cultural deposits in the United States: Early man, J. B. Lippincott Co., London, pp. 61-66, 1937.

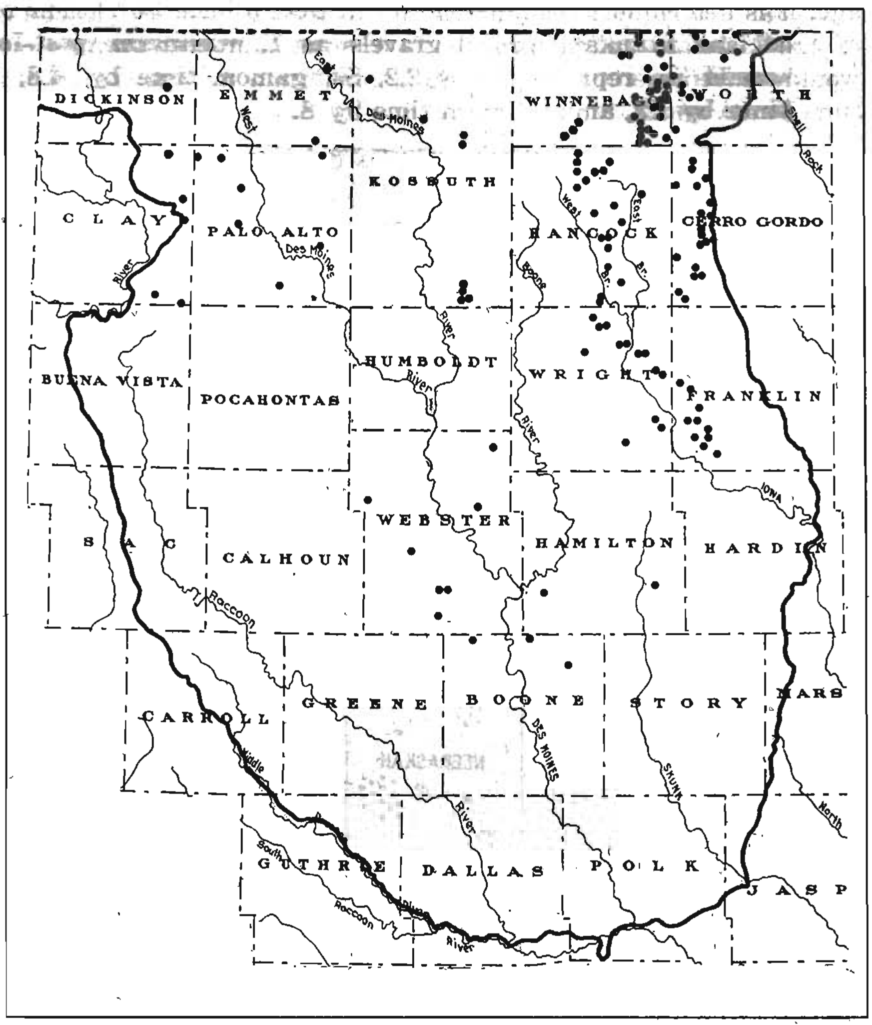

Figure 88. Map of the Mankato drift area in Iowa showing locations of peat deposits.

in detail by Kay.[134] Figure 89 indicates the depth of leaching of upland gravels in the various drift sheets. It may be seen from this comparison that by giving the depth of leaching on the Mankato drift a value of unity, a useful and simple set of ratios may be set up for the relative minimum duration of the weathering of other drift sheets in Iowa. Assuming that the leaching of each fresh drift sheet progressed at a constant rate in each interglacial

[134]Kay, G. F., Classification and duration of the Pleistocene period: Soc. America Bull., vol. 42, pp. 452-466, 1931.

age, it is determined that in relation to the 30 inches of leaching of the Mankato upland gravels as 1, minimum post-Iowan time would be represented by 2.2, Sangamon time by 4.8, Yarmouth time by 12, and Aftonian time by 8.

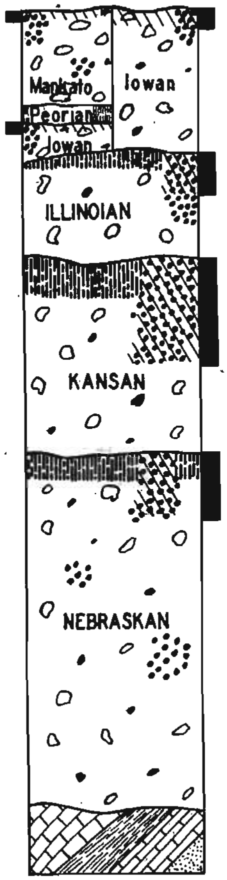

Figure 89. Diagrammatic representation of the depth of leaching of upland gravels in the various drift sheets of Iowa.

The determination of the duration of post-Mankato time in number of years has been attempted along several lines.[135] Among the methods which have received the most study are: the rate of recession of certain waterfalls which began their retreat since the last ice sheet disappeared; the amount of post-glacial erosion where the annual rate can be approximated; the recession of wave-cut cliffs; the counting of overlapping series of varved

[135] Flint, R. F., Glacial geology: Geol. Soc. America, 50th Anniv. Vol., pp. 31-33, 1941.

clays; and the rate of crustal upwarping following ice disappearance. New methods which offer some promise of solution include the study of the rate of radioactive disintegration of hot-spring deposits, the difference between the present magnetic declination and the alignment of magnetic particles in drift sheets, allowing use of the rate of change in magnetic declination, and the rate of recession of the ice front as indicated by a swell and swale pattern produced by seasonal influences.[136]

At the present time, varves have yielded the best results in establishing the chronology of the Recent age, but the method is limited due to the restricted conditions for the formation of varved clays. De Geer in Sweden, and Antevs in America, have had considerable success in this type of investigation. However, the probability of finding as complete a varve series in North America as De Geer has found in Sweden is slight.

All figures of the number of years which have elapsed since Mankato ice receded from northern United States are as yet estimates with broad limits of error. However, an average of estimates based on the several methods of computation indicates that a figure of from 20,000 to 25,000 years for post-Mankato time in the Iowa region is the best figure warranted by our present geological information. This figure has been generally used by geologists, and by anthropologists dealing with early Man.

The need for a dependable figure in years for post-Mankato time is readily apparent. Upon it hinges to a large extent the best determination of the duration of the entire Pleistocene and its constituent epochs.

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[136]Gwynne, C. S., Swell and swale pattern of the Mankato lobe of the Wisconsin drift plain in Iowa: Jour. Geology, vol. 50, pp. 200-209, 1942.

Appendix—Chart I

TABULATION OF PUBLISHED ANALYSES OF LOESS AND LOESS-LIKE MATERIAL[137]

Sample				PERCENTAGE									PERCENTAGE			Sample
No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O-	CO_2	Others and Remarks	No.
1.	75.07	0.68	10.21	2.24	0.43	0.06	1.03	1.78	0.89	1.87	0.29	2.31	1.91	0.62	0.15 ZrO_2, 0.06 Cl, 0.40 SO_3, 0.52 S, 0.17 rare earths, O Cr_2O_3, .03 BaO.	1
2.	63.82	0.77	8.05	1.38	0.27	0.06	3.85	8.27	1.40	0.99	0.35	1.61	1.26	7.15	0.10 ZrO_2, 0.80 total S, O Cr_2O_3 0.02 BaO.	2.
3.	70.86	0.59	8.91	2.97	0.10	0.28	3.12	4.13	1.69	1.18	0.40	1.10		4.70		3.
4.	72.68	0.72	12.03	3.53	0.96	0.06	1.11	1.59	1.68	2.13	0.23	2.50		0.39	0.51 SO_3, 0.09 C	4.
5.	64.61	0.40	10.64	2.61	0.51	0.05	3.69	5.41	1.35	2.06	0.06	2.05		6.31	0.11 SO_3, 0.13 C	5.
6.	76.98	....	....	11.54	....	....	1.68	3.87	....	....	....	2.01		....		6.
7.	77.02	....	....	12.10	....	....	1.63	3.25	....	....	....	2.43		2.83		7.
8.	74.46	0.14	12.26	3.25	0.12	0.02	1.12	1.69	1.43	1.83	0.09	2.70		0.49	0.06 SO_3, 0.12 C	8.
9.	69.66	1.72	12.71	4.89		....	1.28	1.09	1.17	2.42	0.15	....	....	....	0.23 N	9.
10.	60.69	0.52	7.95	2.61	0.67	0.12	4.56	8.96	1.17	1.08	0.13	1.14		9.63	0.12 SO_3, 0.19 C	10.
11.	81.13	0.78	8.52	2.92		....	0.39	0.31	0.52	1.78	0.08	....	....	....	0.11 N	11.
12.	70.63	....	10.43	2.58	0.48	....	1.13	4.64	1.29	2.50	0.20	3.77		2.59		12.
13.	72.312	....	12.664	4.669		....	0.944	1.147	2.472	3.748	0.228	1.797		....		13.
14.	69.27	....	13.51	3.74	1.02	Tr	1.09	2.29	1.70	3.14	0.45	4.19		Tr		14.
15.	60.97	....	15.67	5.22	0.35	Tr	1.60	2.77	0.97	2.28	0.19	9.83		0.31		15.
16.	67.10	....	10.26	2.52	0.31	....	1.24	5.88	1.42	2.68	0.11	5.09		3.67		16.
17.	72.04	....	12.37	3.38	0.37	....	1.22	1.21	1.83	2.58	....	3.15		Tr	1.85 Undetermined. Al_2O_3 includes others of same group.	17.
18.	86.96	0.69	4.69	2.86		....	0.43	0.71	1.07	0.91	0.07	....	....	....	0.11 N	18.
19.	81.51	....	6.02	5.63		0.06	1.08	1.37	0.05	0.89	0.18	2.55	(4.92)	....	0.03 SO_3, H_2O includes organic	19.
20.	76.78	....	7.91	6.88		0.04	1.34	2.00	0.35	1.07	0.13	2.82	(4.98)	....	0.02 SO_3, H_2O includes organic	20.
21.	80.53	....	6.12	6.13		0.07	1.47	2.08	0.24	0.70	0.18	2.35	(3.20)	....	0.02 SO_3, H_2O includes organic	21.
22.	66.69	....	14.16	4.38		0.09	1.28	2.49	0.57	1.21	0.29	4.94		0.77	0.41 SO_3, 0.34 Cl, 2.00 Organic	22.
23.	44.64	....	13.19	5.12		0.13	2.96	13.91	0.59	1.71	0.94	3.84		8.55	0.64 SO_3, 0.14 Cl, 3.43 Organic	23.
24.	88.098	....	....	6.941		....	0.292	0.207	....	1.963	0.118	....	3.100	....		24.
25.	71.09	....	....	16.78	....	....	....	1.81	0.23	1.30	0.11	....	....	0.80		25.
26.	58.97	....	9.97	4.25		....	2.05	11.31	0.84	1.11	....	1.37		11.04		26.
27.	79.53	....	13.45	4.81		....	0.06	0.02	1.14	1.50	....	....	....	....		27.
28.	78.61	....	....	15.26		....	0.91	....	3.33		....	....	....	....		28.
29.	62.43	....	7.51	5.14		....	1.65	9.88	1.75		....	2.31		9.32		29.
30.	81.04	....	9.75	6.67		....	0.27	....	2.27		....	....	....	....		30.
31.	71.56	....	11.40	5.62		....	1.22	0.82	1.21		....	....	....	....	6.95 Organic, incl. 2.45 N	31.
32.	69.8	....	13.5	7.0		....	....	1.6	....	....	....	....	....	....	6.4 Organic, 1.7 Humic acid, Cl, etc.	32.
33.	64.22	....	....	18.1	....	Tr	2.09	6.31	0.22	0.99	....	1.81	0.73	4.1		33.
34.	59.30	0.60	11.45	2.32	1.55	....	2.19	8.35	1.80	2.17	0.20	0.96		8.94	0.20 SO_3	34.
35.	61.23	0.70	11.35	3.50	1.20	....	1.89	7.51	1.65	2.10	0.18	0.64		7.95	0.20 SO_3	35.
36.	62.25	....	14.93	0.74	4.64	0.07	3.00	5.09	4.01	2.02	0.11	2.86	0.34	....	0.06 Cl	36.
37.	15.90	....	9.58	17.42		....	3.26	16.90	....	3.29	....	4.15		33.49		37.
38.	65.04	....	0.40	2.45		....	3.16	6.80	0.02	1.96	1.12	21.97		14.41		38.
39.	64.00	....	0.24	1.56		....	2.58	7.00	1.17	1.90	1.16	21.98		13.69		39.
40.	49.40	....	21.52	7.65		....	....	7.08	2.84	2.96	0.22	8.19		3.77		40.
41.	42.48	....	21.19	7.95		....	2.89	8.16	3.39	3.56	....	23.49		4.81		41.
42.	50.50	....	20.20	7.23		....	2.43	9.50	1.28	2.53	....	20.36		6.71		42.
43.	73.45	....	2.36	4.50		....	....	5.25	....	....	....	9.50		6.48		43.
44.	68.90	....	0.09	1.53		....	2.08	7.37	0.79	1.32	Tr	7.22		13.28		44.
45.	57.5	....	14.3	8.0		....	1.7	8.3	1.7	2.5	0.8	16.5		12.4		45.

[137]A key to the foregoing tabulation of loess analyses appears on the succeeding pages. The key includes the sample number and where possible the locality, literature reference and analyst.

KEY TO TABULATION OF LOESS ANALYSES

Sample No. — Analyst

1. No. 5M, Peorian loess, Johnson County, etc. No reference........L. C. Thomas
2. No. 77M, Peorian loess, Fayette County, etc. No reference........L. C. Thomas
3. Mt. Vernon loess from Cornell campus. Knight, N., Analysis of Mount Vernon loess: Am. Jour. Sci., 4th ser., vol. 13, p. 325, 1902........N. Knight
4. Loess from summit of ridge, Dubuque Iowa. Chamberlin, T. C. and Salisbury, R. D., Preliminary paper on the Driftless Area of the upper Mississippi Valley: U. S. Geol. Survey 6th Ann. Rept., p. 282, 1885........Riggs, U. S. Geol. Survey
5. Loess from 7-foot stratum overlying residual clay, Galena, Illinois. Chamberlin, T. C. and Salisbury, R. D., idem., p. 282........Riggs, U. S. Geol. Survey
6. Loess from Hannibal, Missouri. Hayden, F. V., Final Rept. of the U. S. Geol. Survey of Nebraska and portions of the adjacent territories: U. S. 42nd Cong. 1st sess., House Exec. Doc. 19, p. 12, 1872; Aughey, S., Sketches of the geography and geology of Nebraska, p. 267, Omaha, 1880
7. Loess from Hannibal, Missouri. Hayden, F. V., idem., p. 12; Aughey, S., idem., p. 267.
8. Loess from Kansas City, Missouri. Chamberlin, T. C. and Salisbury, R. D., op. cit., p. 282........Riggs, U. S. Geol. Survey
9. Loess soil, Cherokee, Kansas. Bennett, H. H., The soils and agriculture of the southern states, New York, Macmillan Co., 1921.
10. Loess from Center Vicksburg, Mississippi. Chamberlin, T. C. and Salisbury, R. D. op. cit., p. 282........Riggs, U. S. Geol. Survey
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14. Denver loess, 8 feet below surface on boulevard near Ashland Ave., Denver, Colorado. Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 514, 1924........Eakins, U. S. Geol. Survey
15. Early loess, 20 feet below surface near St. Luke's Hospital, North Denver, Colorado. Clarke, F. W., idem., p. 514........Eakins, U. S. Geol. Survey
16. Loess from surface round near State House, Cheyenne, Wyoming. Clarke, F. W., idem., p. 514........Eakins, U. S. Geol. Survey
17. Loess, one mile east of Alta, Wyoming. Blackwelder, E., Post-Cretaceous history of western Wyoming: Jour. Geology, vol. 23, p. 338, 1915........W. C. Wheeler, U. S. Geol. Survey

18. Silt loam, Weeping Water. Lyon, T. L. and Buckman, H. O., The nature and properties of soils; a college text of edaphology, New York, Macmillan Co., 1922; Barbour, G. B., Loess of China (with bibliography): Smithsonian Inst. Ann. Rept. for 1926, 1927.
19. "Dust soil" from plateau on Willow Creek, Morrow County, Oregon. Hilgard, E. W., A report on the relations of soil to climate: U. S. Dept. Agr., Weather Bureau, Bull. 3, 1892; Merrill, G. P., A treatise on rocks, rock-weathering and soils, p. 345, New York, Macmillan Co., 1897.
20. "Dust soil" from Atathnam prairie, Yakima County, Washington. Hilgard, E. W., idem.; Merrill, G. P., idem., p. 345.
21. "Dust soil" from Rattlesnake Creek, Kittitas County, Washington. Hilgard, E. W., idem.; Merrill, G. P., idem., p. 345.
22. Adobe from Santa Fe, New Mexico. Merrill, G. P., idem., p. 334.
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27. Loess from road between Oberdollendorf and Heisterbach, deducting carbonates and loss on ignition. Bischof, C. G. C., idem., p. 127.
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CERAMIC SHALES AND CLAYS OF IOWA

by

CHARLES S. GWYNNE

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CERAMIC SHALES AND CLAYS OF IOWA

BY CHARLES S. GWYNNE

Abstract

In this paper fundamentals of the geology and technology of the shales and clays of Iowa are dealt with. The uses, mineral composition, manner of occurrence and origin of these deposits are first considered. The distribution and character of the most important geologic units containing ceramic shales and clays are then described. Most attention is given to the Pennsylvanian Des Moines series, which underlies much of the central and southern parts of the State, and which is accessible at many places. Appropriate attention is given to other shale and clay horizons, the materials of which are used by ceramic plants. These include the surface clays, and the shales occurring in the Juniper Hill member of the Devonian Lime Creek formation, the Devonian Sheffield formation and the Cretaceous system. The shale of the Ordovician Maquoketa formation and the clay of the Silurian Niagaran series of northeastern Iowa are also considered, since these materials have either recently been used or their use considered.

Samples of these shales and clays were secured most of them from the pits of producing plants, and a few from natural outcrops. Thirty-six of these have been tested by methods recommended by the Standards Committee of the American Ceramic Society and the data are included. While those tested have been found to vary somewhat in their ceramic properties, most of them are shown to be suitable for the manufacture of heavy clay products such as brick and tile. Forty-five chemical analyses of shales and clays are included, through the courtesy of cement manufacturers.

INTRODUCTION

Many of the shale and clay deposits of Iowa are suitable for the manufacture of ceramic ware such as brick, drain tile, building tile and pottery. They were used by the Indians in the making of pottery and by the earliest settlers in the making of brick. Over the past few decades the annual value of the ware produced has averaged well over a million dollars. In more recent decades they have also been used in great amount in the manufacture of portland cement, the annual value of which also runs into millions of dollars. Thus these materials, widespread and easily available, have demonstrated their suitability and their value, and must be considered an important mineral resource of the State. The wealth produced by the brick, tile and pottery plants of the present and the past, and by the cement plants, would be nonexistent were it not for these raw materials.

In spite of their abundance, the origin, the way in which they occur and the physical characteristics of these materials are none too well known to many citizens. Much has been written regarding them in the past. Volume 14 of the Iowa Geological Survey in particular dealt with them exhaustively. This, however, was published 40 years ago. Since that time, while the geology of the shales and clays has not changed, much has been learned concerning them. In addition the clay-working industry has undergone great changes in the number of plants, the raw material used, the methods of manufacture and in other phases. In view of such facts it seems reasonable that a description of these deposits and of associated matters related to their use should be of value to citizens of the State and to others. This paper is intended as such a description.

It is intended to make it rather non-technical, so that persons without acquaintance in the field of geology may acquire a reasonable understanding of the matters under discussion. It is hoped that the report will be of value to the clay products manufacturer or worker, to those having shale or clay deposits on their lands and to those having a general interest in the subject. Many of the shales and clays have been sampled and tested for ceramic properties in the course of this study, and the results of the tests are described. This part of the report, of a more technical nature, should be of particular interest to the manufacturer of clay products.

Following consideration of the previous writings on the shales and clays of Iowa and of the history of their uses, the geology and mineralogy of shales and clays in general will be described. The general geology of the shales and clays of the State will next be considered, followed by sections devoted to each one of the shale or clay producing horizons. In those sections such matters as the extent and thickness, depth beneath the surface, character, and associated rocks for each producing horizon will be considered. Particular attention will be paid to descriptions of the material of the shale pits of the plants which are at present operating. Finally the tests made on samples taken from operating pits will be described, as will the results. Information regarding the extent of the industry will also be introduced.

PREVIOUS STUDIES OF SHALES AND CLAYS OF IOWA

The Iowa Geological Survey has throughout its existence devoted a proportionate part of its work to consideration of the shale and clay resources of the State. The results of the studies enter into many of the publications of the Survey, beginning with Volume 1, appearing in 1892, and continuing through the most recent one, Volume 37, published in 1941.

During these years the Survey has completed reports on the geology of most counties of the State. Each of these describes the geology of the county including that of the deposits containing shale and clay. The economic geology is also described, and in these sections of the reports the ceramic industry of the county is dealt with, including a discussion of its raw material, the plants in operation, their equipment and other pertinent subjects.

The mineral production in Iowa from year to year has also been reported in various volumes. These mineral production reports are concerned chiefly with matters such as the annual value of the products and changes in the industry.

The most complete report on the clay and shale resources and industry of Iowa is that of Volume 14 of the Survey, published in 1903. This includes the following sections:

Technology of clays. S. W. Beyer and I. A. Williams.
Chemistry of clays. J. B. Weems.
Selection, installation, and care of power plants. G. S. Bissell.
Geology of clays. S. W. Beyer and I. A. Williams.
Tests of clay products. A. Marston.
Directory of clay workers. S. W. Beyer and I. A. Williams.

This report was thorough and dealt with some matters which will not be considered here. In particular, no attempt will be made to describe equipment and methods here.

The refractory and semi-refractory shale and clays of Iowa were investigated by Galpin[1] in an attempt to locate commercial deposits of high grade refractory materials. He has described the occurrence, characteristics and ceramic properties of those shales and clays which were thought to have possibilities in the manufacture of refractory ware. The properties of the known Iowa refractory clays had previously been reported upon by Beecher.[2]

Publications of the Survey have been drawn upon freely in the preparation of this report. In addition to those mentioned above much use has been made of the geologic map of the State.[3] This map provides the best information with regard to the areal distribution of the shale and clay-bearing formations of the bedrock over most of the State.

USES OF IOWA SHALE AND CLAY

Ceramic ware. Shales and clays have proven to be an important resource of Iowa almost since its earliest settlement, for with the settlement there developed a brick and tile industry dependent upon

[1]Galpin, S. L., The geology of the more refractory clays and shales of Iowa: Iowa Geol. Survey, vol. 31, pp. 53-91, 1925.
[2]Beecher, M. F., An investigation of the Iowa fire clays: Engineering Experiment Station, Iowa State College, Bull. 40, 1915.
[3]Tester, A. C., Geologic map of Iowa, Iowa Geol. Survey, 1937.

these materials. Tile was needed for drainage, brick for construction of paved city sidewalks and streets, brick and later building tile, for construction of dwellings and other buildings, and sewer pipe for construction of sewage systems. Pottery and stoneware plants also were built. Shale and clay were even burned to produce a rock-like material useful as railroad ballast in parts of the State where other forms of ballast were lacking. The ceramic industry became extensive, and in 1902 there were 329 large and small producers of clay products scattered about the State. Most of these were small plants and usually supplied a restricted local demand, particularly for brick and drain tile.

During the past three decades the number of ceramic plants in Iowa has gradually decreased until at present there are only approximately 28 plants operating or in condition to operate. These are engaged almost entirely in the manufacture of heavy clay products such as brick, drain tile, building tile and sewer pipe. The manufacture of pottery and stoneware has almost ceased. One small plant has, until recently at least, made flower pots and a few others have made art pottery. Occasionally plans arise for extensions of the pottery industry on a small scale, but this is not of great significance in the use of the shale and clay resources.

While the number of companies engaged in the manufacture of clay products has decreased greatly, the value of the annual production has increased and continues large. In 1929 it amounted to a total of $5,791,195. It decreased in subsequent years, but has more recently again mounted as shown by the following table:[4]

1932	$ 796,445
1933	842,726
1934	1,352,227
1935	2,006,021
1936	2,728,810
1937	3,250,677
1938	2,868,233

These changes in the distribution and extent of the industry have been accompanied by changes in the raw material used. Thirty years ago the surface clays were most widely used. Gradually the shales and clays of the bedrock have become the principal raw material, although surface clay is used in part at many of the plants.

The decrease in the number of clay products plants has obviously not been due to the exhaustion of supplies of raw materials. Clay and shale suitable for the manufacture of the more common wares

[4]Hershey, H. G., Mineral production in Iowa—1933-1938: Iowa Geol. Survey, vol. 37, p. 386, 1941.

are available in Iowa, as they are in other states, in enormous quantity. Other factors have played a greater part in the changing structure of the ceramic industry of Iowa. These include the cost of the shale and clay, dependent in turn upon matters such as the amount of overburden which must be moved, the presence or absence of non-ceramic materials such as limestone or sandstone interstratified with the shale, and the general cost of pit operation and hauling; location of plant with respect to markets; cost of plant operation; and the quality of the product. The history of the industry in other midwestern states has been in many respects similar to that of Iowa for the same general reasons.

Iowa lacks proved deposits of shale and clay suitable for the manufacture of higher grade products such as fire brick and china. Some localities in other midwestern states possess advantages in the manufacture of the heavy clay products, not of superior shales or clays, but of better transportation facilities or of more extensive markets.

The companies at present (1942) operating in Iowa are listed below, together with the location of their plants, the kinds of ware produced and the monthly capacities where known.

Iowa Brick and Tile Manufacturers, Products and Capacities

Company and Location	Products	Estimated Monthly Production Tons
Adel Clay Products Co., Redfield, Dallas County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile.	3,500
Carlisle Brick and Tile Co. Carlisle, Warren County	Common brick, face brick, structural clay tile, unglazed facing tile.	800
Clermont Brick and Sand Co. Clermont, Fayette County	Common brick, drain tile.	....
Des Moines Clay Co. Des Moines, Polk County	Common brick, face brick.	2,500
Centerville Clay Products Co. Centerville, Appanoose County	Common brick, face brick.	1,800
Garrison Brick and Tile Co. Garrison, Benton County	Common brick, drain tile.	400
Gladbrook Press Brick and Tile Co. Gladbrook, Tama County	Common brick, face brick.	1,000
Goodwin Tile and Brick Co. Des Moines, Polk County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile.	2,000

Iowa Sewer Pipe and Tile Co. Des Moines, Polk County	Drain tile, sewer tile, wall coping.	....
Johnston Clay Works Fort Dodge, Webster County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile, salt glazed brick and tile.	3,500
Kalo Brick and Tile Co. Kalo, Webster County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile, salt glazed brick and tile.	4,000
Kimballton Brick and Tile Co. Kimballton, Audubon County	Common brick, drain tile.	200
Lehigh Sewer Pipe Co. Lehigh, Webster County	Sewer pipe	....
Mason City Brick and Tile Co. Mason City, Cerro Gordo County	Common brick, face brick, sewer brick, structural clay tile, unglazed facing tile, drain tile.	15,000
F. C. McHose & Son Nevada, Story County	Common brick, structural clay tile, drain tile.	400
Nelson Clay Works What Cheer, Keokuk County	Common brick, tile and art pottery.	....
Oskaloosa Clay Products Co. Oskaloosa, Mahaska County Harvey, Marion County	Common brick, face brick, structural clay tile, salt glazed brick and tile.	1,800
Ottumwa Brick and Tile Co. Ottumwa, Wapello County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile.	800
Redfield Brick and Tile Co. Redfield, Dallas County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile.	2,500
Rockford Brick and Tile Co. Rockford, Floyd County	Common brick, face brick, sewer brick, structural clay tile, unglazed facing tile, drain tile.	2,500
Sheffield Brick and Tile Co. Sheffield, Franklin County	Common brick, face brick, sewer brick, structural clay tile, unglazed facing tile, drain tile.	2,500
Sioux City Brick and Tile Co. Sioux City, Woodbury County Sergeant Bluff, Woodbury County	Common brick, face brick, sewer brick, structural clay tile, unglazed facing brick, salt glazed brick and tile.	7,000 3,000
United Brick and Tile Co. Adel, Dallas County	Common brick, face brick, unglazed facing tile, structural clay tile, drain tile.	2,500
Vincent Clay Products Co. Fort Dodge, Webster County	Common brick, face brick, structural clay tile, unglazed facing tile, drain tile, salt glazed brick and tile.	3,000
What Cheer Clay Products Co. What Cheer, Keokuk County	Drain tile, sewer tile, wall coping.	....
Winfield Brick and Tile Co. Winfield, Henry County	Common brick, drain tile.	200

The structural clay products named in the foregoing are defined below:

Common Brick: A brick made primarily for building purposes and not especially treated for texture or color.

Face Brick: Brick made especially for facing purposes, usually treated to produce surface texture or made of selected clays or otherwise treated to produce a desired color.

Paving Brick: A brick with good abrasive resistance made primarily for street or walk paving.

Sewer Brick: A brick relatively chemically inert made primarily for sewer construction or sewer lining.

Floor Brick: A brick with properties similar to paving brick but manufactured with greater precision and usually treated to produce a desired color.

Structural Clay Tile: A hollow clay tile made primarily for building purposes and not especially treated for texture or color.

Unglazed Facing Tile: A hollow clay tile made primarily for facing purposes, usually treated to produce surface textures or made of special clays or otherwise treated to produce a desired color but without the addition of a surface glaze.

Drain Tile: A circular tile made primarily for land drainage of subsurface water.

Ceramic Glazed Brick or Tile: A brick or tile with surface glazing produced by the direct application of a glazing material to the surface.

Salt Glazed Brick or Tile: A brick or tile with surface glazing produced by condensation of a volatilized metallic salt on the surface.

Portland cement. The shales and clays of the State are also used in making portland cement, in the manufacture of which a considerable percent of argillaceous or clayey substance, as well as limestone, is required. The composition of the limestone may be such that not much additional shale or clay is needed, but the percentage of shale or clay required may total as much as 25 percent if the available limestone is almost pure. Thus the cement plants of Des Moines, West Des Moines, Mason City and Davenport are important users of shale or clay in cement, although it is difficult to arrive at the value of the raw material used.

Mortar mix. Finely ground shale and clay are also used in the building industry as "mortar mix". This contributes to plasticity when added to the mortar in small amount. The mortar is said to "work" better, to smooth more easily and to fill small holes and crevices more completely. Value of the ground shale sold for this purpose in 1938 is believed to have totaled approximately $30,000.

Road surfacing and railroad ballast. The production of railroad ballast by burning clay was a simple one. It consisted of piling up layers of clay and of old railroad ties and similar combustible material, and setting fire to the pile. The use of burned shale and clay as railroad ballast was discontinued many years ago. In recent decades, however, the partially burned shale and other refuse of coal mines has been widely used for road surfacing and for surfacing the shoulders of concrete highways, and possibly for railroad ballast. This refuse contains not only shale and clay from the mines, but also more or less associated coal. The coal ignites, possibly as a result of the heat generated in weathering of the coal or contained impurities, and the shale and clay are partially vitrified. The material serves usefully when better materials such as gravel and limestone are not available.

VALUE OF CLAY AND SHALE

The highest quality shales or clays, unprocessed and in bulk, are not expensive materials, and even those of lower quality but still limited in distribution are relatively low-priced. The following table[5] gives values for the clays which are sold in quantity in the United States.

Average values per short ton of various kinds of clay sold by producers in the United States, 1909-13 and 1925-34.

Year	Kaolin and Paper Clay United States	Ball Clay	Slip Clay	Fire Clay	Stoneware Clay
1909-13 (average)	$5.34	$3.65	$1.81	$1.39	$1.00
1925-29 (average)	8.45	7.67	5.41	2.76	2.12
1930	7.29	7.91	6.02	2.38	1.93
1931	6.65	7.71	7.10	2.54	2.30
1932	5.83	6.57	9.72	2.83	1.66
1933	5.75	6.21	7.28	2.77	2.11
1934	6.33	6.73	7.00	2.90	1.77

These values include cost of quarrying and possibly processing as well, and it is notable that even fire clay of marketable quality, higher in quality than that of Iowa, is not very costly. Stoneware clay, really a low-grade fire clay, has a still lower value.

Common shale and clay suitable for use in making heavy clay products has even less market value than stoneware clay if sold unprocessed. It has a greater market value when ground and sold in small quantities for special purposes, as for mortar mix or clay modeling, but the market for such purposes is limited. Kaolin and ball clay are white-burning clays used in high quality products such as chinaware, and slip clay is a clay of low fusibility used in glazes and as a binder in abrasives. They command a higher price because of their scarcity. There is believed to be little or no prospect of any of these more valuable clays being found in commercial quantity in Iowa.

[5]Tyler, P. M., and Metcalf, R. W., Clay: Minerals Yearbook 1935, p. 984, 1935.

GENERAL GEOLOGY OF CLAY AND SHALE

Definition. Clay, from the ceramist's viewpoint, is a naturally occurring earthy substance which will mold when wet, retain its shape when dry, and harden to a rock-like substance upon cooling after being subjected to a sufficiently high temperature, a process known as burning or firing. Shale is similar in properties, but is commonly more compact and rock-like, stratified, and occurs in more or less definite layers, usually beneath the subsoil. Shale, to the geologist,[6] is a fine-grained, fissile, argillaceous, sedimentary rock characterized by rather fragile and uneven laminae and commonly a somewhat splintery fracture. In any case shale is generally considered to be a consolidated mud or clay, consolidated by pressure, or cementation, or both. There is obviously no sharp division between the consolidated and the unconsolidated clay.

Origin of clay. Clay originates through the breaking down of other rocks, and the individual particles of clay are the smallest produced in this breaking-down process. Most of the particles of clay originate through the natural process known as weathering. This process is in part a chemical one, brought about by the gases of the atmosphere, water, carbon dioxide, oxygen and possibly other constituents present in minor amount; and by the subsurface water with its content of dissolved carbon dioxide, oxygen, weak organic acids derived from the decay of vegetation, and occasionally weak inorganic acids derived from the weathering of minerals. Weathering is also in part a physical or mechanical process brought about by volume changes induced by chemical weathering and possibly by temperature changes, the freezing of water in cracks, and the splitting and prying action of plant roots.

Most of the minerals of the primary rocks such as granite are changed to other substances by this process. Some of these substances are soluble in water and are leached away. Others, insoluble and inert to further change and in particles of microscopic size remain, unless removed by running water, wind, or glacial ice. Some of the minerals of the primary rocks such as quartz are quite inert and remain essentially unchanged in the midst of the mass of clay-like material thus derived from the less inert minerals. The final product is essentially a clay, possibly containing quartz grains and insoluble weathering products such as limonite, a hydrated iron oxide.

[6]Fay, A. H., A glossary of the mining and mineral industry: U. S. Bur. Mines Bull. 95, p. 606, 1920.

Residual clay. This weathering process just described will produce a clay-like mass from most rocks. Unless subjected to active erosion this product will rest upon the rock from which it was derived and will grade to it through less and less weathered material. Such material is known as residual mantle and as residual clay if it is high in clay. Commercial deposits of high grade white residual clay such as occur in North Carolina are derived from rocks lacking in iron-containing minerals. Such clays, in part because of their freedom from iron, can be used in the manufacture of high grade ceramic products such as china ware and porcelain. There are, however, extensive areas underlain by residual clay that have no great value because of the admixture of limonite, and grains and larger fragments of inert minerals and rocks. Residual clays are unimportant in Iowa, although present above the bedrock in some places.

Alluvial clay. All other clay and shale deposits are derived chiefly from the clay of residual mantle, although a considerable proportion of the particles of clay-like size may have been derived from the solid rocks of the streams and bedrock by the erosive agents, particularly running water. Running water has great sorting power, whereby particles of one grain size are laid down together as the running water loses velocity. This leads to the formation of deposits of clay as well as of silt, sand and gravel along the valleys, particularly of the larger streams. Thus, deposits of alluvial clay are present along many of the rivers and smaller streams of Iowa and have been used to some extent in the manufacture of ceramic products. They constitute a type of transported mantle, as do the deposits made by glaciers, lakes and the wind.

Glacial clay. Glaciers, such as those which have in time past covered all of Iowa and much of the upper Mississippi and Ohio River basins, have left great deposits of clay mixed with particles of larger size. This glacial clay, till, or boulder clay, as it is variously called, is comprised chiefly of particles of clay size, but also contains considerable amounts of silt, sand, pebbles, cobbles and boulders in heterogeneous mixture. Much of this material has been freed from the bedrock by weathering but a considerable proportion is the result of glacial wear upon solid rock. Much of the subsoil of Iowa, visible in road and stream cuts, is glacial clay. It may be associated with deposits of sand and gravel formed by glacial meltwater.

Lacustrine clays. Lacustrine clays, another type of transported clay, are formed by the deposition of clay on lake bottoms. The lake may gradually be filled and, aided by other causes, finally disappear. The lacustrine clays thus come to be the mantle or subsoil beneath essentially level areas of greater or less extent. Lake plains of this origin are present in many places in the northern United States and Canada, but are of only small extent in Iowa. Such clays are used for ceramic purposes in some places.

Loess. The wind has deposited over great areas of Iowa, adjacent states, and other parts of the world, a blanket of silt and clay called loess. Much of this material in this region is believed to have been derived from glacial meltwater. As the ice melted, the flood plains of the larger rivers were repeatedly flooded. Silt and clay were deposited as the floods subsided. As the surface dried out the particles were swept up by the wind and dropped elsewhere. While the loess grains are for the most part silt size rather than clay, there is nevertheless usually a considerable proportion of clay present, either original or secondary, derived from the weathering of the deposited material. In any case many occurrences are claylike and are used for ceramic purposes. They have been widely used in Iowa.

Marine and estuarine clays and shales. Most of the argillaceous rock in the bedrock of Iowa, that used by most of the ceramic plants, is marine in origin. It has been formed by deposition in the sea or in estuaries at times when the distribution of land and sea was far different than at present. The beds are interstratified with the hardened products of other sediments deposited in the ancient seas, including limestone, sandstone and conglomerate. The seas during times past have transgressed slowly over the continents many times and in them have been deposited the limy or calcareous ooze, mud or clay, sand and gravel that were subsequently to form the limestone, shale, sandstone and conglomerate respectively of the bedrock of today. Coal, another interstratified material, was formed as peat in ancient swamps. The coal usually lies upon an argillaceous material which is called an underclay. It lacks the stratified character of shale although it may grade to shale, has an irregular blocky or starchy fracture, and differs in its ceramic properties from the shales in that it burns at higher temperatures and produces ware that is some shade of buff rather than red in color. These underclays, or fire clays, as they are often called, have presumably originated through changes in the subsoil of the areas in which the plants of the peat-forming areas grew.

They are lower in iron and in elements which lower the fusibility of the ware made from them. They are more highly prized than most of the shales of the bedrock which can be used only in non-refractory, lower-burning products. If lacking in certain undesirable impurities, particularly iron in the form of the minerals limonite and pyrite, they can be used in the manufacture of refractory bricks and buff-colored brick and building tile, products which command a higher price than those made from the shale of the bedrock.

Surface clays. Deposits of any of the foregoing, but particularly those of glacial clay, alluvium, lacustrine clay and loess are changed at the surface by further weathering. Calcium carbonate (lime) is dissolved out, some minerals are changed to clay, and sand and silt grains are reduced in size. The result is a material referred to here as surface clay, which is plastic, usually dries without cracking, and can be burned to reasonably satisfactory brick and possibly tile. It has some advantages over other materials, one of them being that it can be worked practically from the sod down. The deposits, however, are not so thick, and the area which must be worked for clay is relatively large. Much surface clay also undergoes high shrinkage in drying, frequently with much cracking of the ware, and it does not burn as uniformly nor as quickly as shale.

TABLE 1

GENERALIZED GEOLOGIC SECTION OF IOWA

System	Series	Group	Formation	Approx. thickness (in feet)	Character
Cretaceous	Upper Cretaceous	Colorado	Carlile	100+	Shale
			Greenhorn	25–50	Limestone and shale
			Graneros	100–200	Shale
	? Lower Cretaceous	Dakota		100–200	Sandstone and shale
Permian (?)			"Fort Dodge beds"	Up to 50	Gypsum and shale
Pennsylvanian	Virgil	Wabaunsee		300	Limestone and shale
		Shawnee		110–175	
		Douglas		20–120	Sandy shale
		Peedee			
	Missouri	Lansing		25	Limestone, shale and coal
		Kansas City		160–180	
		Pleasanton		15–60	
	Des Moines	Appanoose-Henrietta		125–250	Shale, sandstone, coal and limestone
		Cherokee		350–450	
Mississippian		Meramec	Ste. Genevieve	30–50	Limestone, massive, with sandstone beds
			St. Louis	30–65	Limestone
			Spergen	0–20	Limestone and dolomite
		Osage	Warsaw	70	Limestone and dolomite, cherty and shaly
			Keokuk	70	Limestone and dolomite, cherty
			Burlington	70	Limestone and dolomite, cherty
			Gilmore City	45	Limestone, oolitic
		Kinderhook	Hampton	0–250	Limestone and dolomite, oolitic and cherty
			English River	0–25	Siltstone
			Maple Mill	0–370	Shale
?	?	?			
Devonian	Upper Devonian		Sheffield	125	Shale, thin dolomites
			Lime Creek (State Quarry 0–40' thick)	120–150	Limestone, dolomite and shale
			Shell Rock (State Quarry 0–40' thick)	30–75	Limestone and dolomite
			Cedar Valley	90–150	Limestone
			Independence (?)	0–20	Shale
	?	?			
	Middle Devonian		Wapsipinicon	100–120	Limestone and dolomite, shale
Silurian	Niagaran		Gower	100	Dolomite
			Hopkinton	40–200	Dolomite
	Alexandrian		Kankakee	40	Dolomite, cherty
			Edgewood	6–45	Dolomite, argillaceous
Ordovician	Cincinnatian	Richmond	Maquoketa	0–300	Shale, limestone and dolomite, cherty
	Mohawkian	Trenton	Galena: Dubuque	30	Limestone and dolomite
			Galena: Stewartville	60	Limestone and dolomite
			Galena: Prosser	135–180	Limestone and dolomite, cherty
			Decorah	30	Shale and limestone
		Black River	Platteville	50	Shale and limestone
	Chazyan		St. Peter	50–238	Sandstone
	Beekmantownian		Prairie du Chien: Willow River	75–90	Dolomite, sandy and cherty
			Prairie du Chien: Root Valley (New Richmond)	20–25	Sandstone, dolomitic
			Prairie du Chien: Oneota	140–170	Dolomite, sandy and cherty
Cambrian	St. Croixan		Trempealeau: Madison, Jordan, Lodi, St. Lawrence	150–185	Dolomite, sandy; Sandstone, dolomitic; Siltstone to sandstone; Dolomite, sandy
			Franconia	160	Sandstone and dolomite, glauconitic
			Dresbach: Galesville, Eau Claire, Mt. Simon	550	Sandstone
Pre-Cambrian (Huronian)			Sioux		Quartzite

COMPOSITION OF SHALE AND CLAY

Mineral composition. Shale and clay consist of grains or particles less than 0.004 millimeter in diameter, derived from many sources and from many kinds of pre-existing rocks and minerals. Shale and clay particles are those below a certain size, and are not of a specific composition or origin. Most of the particles are grains of the "clay" minerals, derived from the chemical weathering of other silicates. These clay minerals are soft, white, scaly minerals in flakes of microscopic size. There are commonly other clay-like minerals in clay deposits, including partially weathered mica and chlorite. Finally there are irregularly shaped grains of minerals such as quartz and feldspar which do not contribute to the clay-like character of the shale and clay. Such minerals commonly form the particles of silt size, ranging up to 0.06 millimeter in diameter which are found in most clay and shale deposits. Particles of sand size, ranging to 2 millimeters, are principally of quartz.

There are several clay minerals or groups, but most of the common clay and shale is composed of members of the beidellite-montmorillonite group. Red or brown shales or clays contain appreciable quantities of the minerals limonite or hematite. Calcareous or limy shales and clays contain the mineral calcite, commonly referred to as lime. Dark gray and black shales and clays contain carbon derived from plant fragments. Pyrite is present in nodules and small crystals in many shale and clay deposits.

Shales and clays also contain a variable amount of extremely fine material known as colloidal matter. The clay minerals and the colloidal matter are principally responsible for the plastic properties of these substances.

Chemical composition. The clay minerals are primarily hydrated aluminum silicates composed of the elements hydrogen, oxygen, aluminum and silicon, and some of them contain in addition small amounts of the elements calcium, magnesium, iron and potassium in their composition. Micas and feldspars are aluminum silicates, containing in addition to silicon, oxygen and aluminum, small amounts of elements such as potassium, sodium, calcium, magnesium and iron. Quartz is silicon dioxide, hematite is iron oxide, and limonite is hydrated iron oxide.

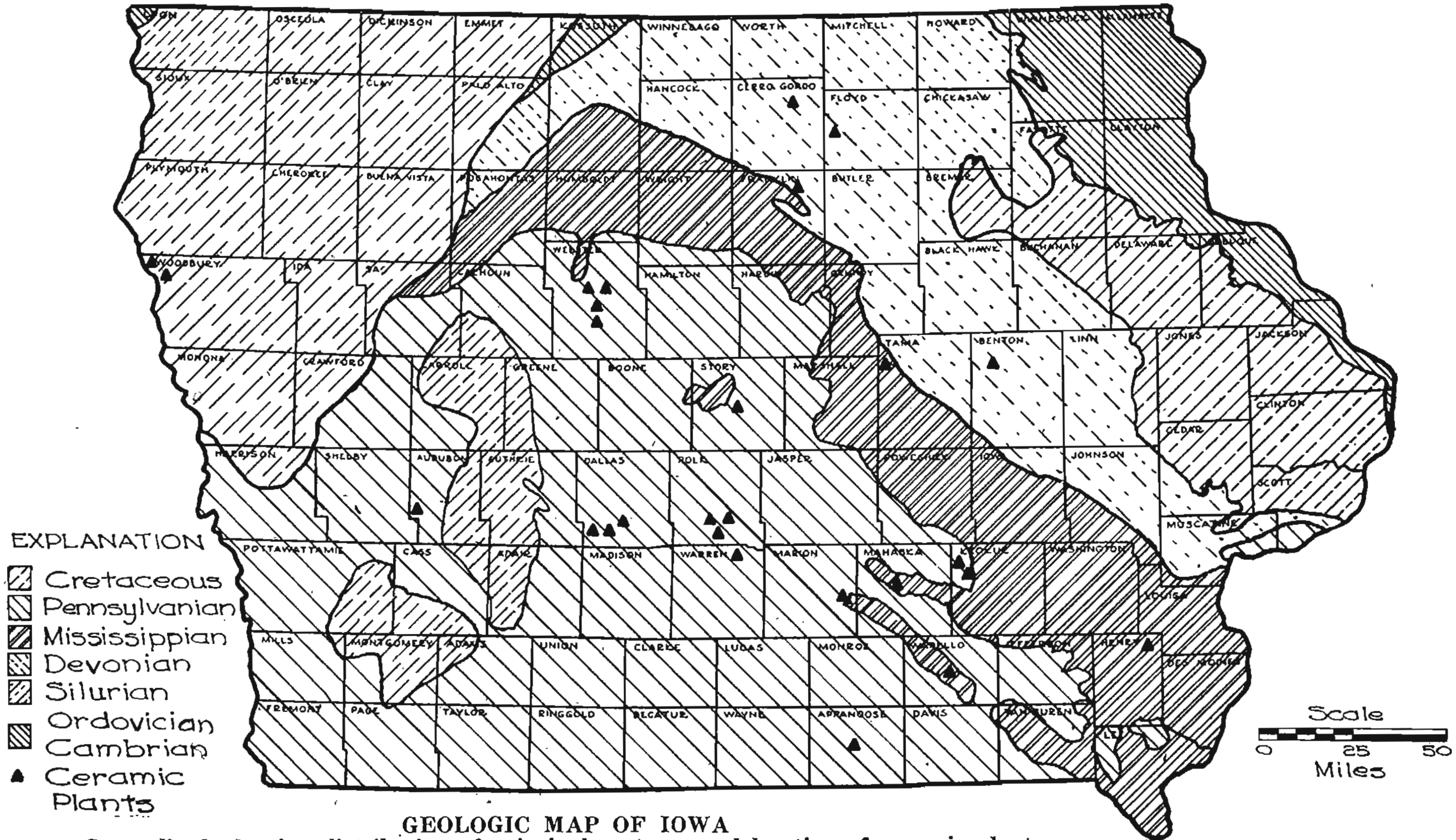
A deposit of shale or clay may thus range in chemical composition from that of a hydrated aluminum silicate to one containing relatively important amounts of iron, magnesium, calcium, sodium and potassium. The presence of these latter contributes to the low burning point of the material. Shales and clays free from those elements have a high burning temperature and produce a white product. Clays high in silt or sand generally are high in silicon dioxide. Chemical analyses of shale and clay are given at the end of this paper.

GENERAL GEOLOGY OF THE SHALES AND CLAYS OF IOWA

Directly beneath the topsoil of most of Iowa there are the materials making up the soil and subsoil, commonly known as mantle. These include chiefly loess, glacial clay and alluvial clay, but sand and gravel are present in considerable amount. Beneath these is the solid rock or bedrock containing the extensive deposits of shale and clay which are most widely used today. For an understanding of the distribution and relations of the shale and clay of the bedrock, it is believed advisable to consider briefly the geology of the State as a whole.

With the exception of a small area in the northwestern corner, the bedrock beneath the mantle is sedimentary rock. As already noted in the discussion of the origin of shales and clays, the beds of which this sedimentary rock is composed were originally laid down as sediments in shallow seas, which at various periods have covered the respective areas. The sediments have since hardened and consolidated to varying degrees due to the pressure of overlying beds and the cementation by substances deposited by ground water.

These sedimentary rocks are in broad sheets or lenses, some of great areal extent, one above the other, and are for the most part limestone, shale and clay, and sandstone. Except for those at the top beneath considerable areas in the western counties, they have the form of a shallow trough, the axis of which plunges gently southwestwardly from Winnebago County. Because of this structure the areas of outcrop or surface distribution of the various units are arranged in irregularly shaped belts of varying width which trend from the northwest to the southeast across central and eastern Iowa. They dip on the average approximately 8 feet to the mile. The older units, those at the bottom of the column, are at the surface in the northeastern corner of the State, and successively younger ones are at the surface toward the southwest.



GEOLOGIC MAP OF IOWA
Generalized, showing distribution of principal systems, and location of ceramic plants.

The geologists have given appropriate names to eras and periods of earth history, and refer to the rocks formed in eras and periods as sequences and systems respectively. The systems are further subdivided into series and formations. The accompanying generalized geologic map, plate I, shows the surface distribution of the geologic systems at the top of the bedrock in Iowa. The columnar section, table 1, gives generalized information regarding the subdivisions, their thicknesses and character.

There are many shale beds in the section beginning near the bottom with the Platteville formation of the Ordovician system. Many of these are not suited to ceramic uses because of high lime content or the presence of interbedded limestone. Others are too thin or lie beneath thick overburden. The particularly important ones, used widely in the ceramic industry and in some cases in the cement industry, are:

The Juniper Hill member of the Lime Creek formation of the Upper Devonian series.
The Sheffield formation of the Upper Devonian series.
The Des Moines series.
The Cretaceous system.

The Maquoketa formation is of less importance, and the Niagaran series is only of interest because of the presence of white-burning clays. Each of those named in the foregoing will be considered in the following pages.

These formations usually are exploited along valley sides, because the mantle overburden is least in such localities. They are thin because so much has been removed in the process of valley development. Where valleys are numerous, many of them deep, and where the mantle is thin, there may be many outcrops of the bedrock in a single county. Outcrops of the bedrock are absent in other counties in which the mantle is thick and the terrain but slightly eroded. Well records or the records of mining operations are then the only source of information regarding them.

The distribution and character of each of these units containing shale and clay important to the ceramic industry will be described in subsequent pages. The use of surface clays will also be briefly considered.

SURFACE CLAYS

Surface clays, in a ceramic sense, are clays which lie below the top soil and which can be used in the manufacture of ceramic ware. Geologically, such clays are the products of the weathering of the underlying clayey mantle, which may be alluvium, glacial clay or loess. Some so-called surface clay is also derived from the softening and weathering of shale in the bedrock beneath.

The surface clays derived from alluvium, glacial clay and loess are widespread through Iowa. Loess and alluvium formed by the reworking of loess are believed to constitute the parent material of most of the desirable surface clay, although glacial clay is also important. Weathering acts to remove lime, to reduce the amount of silt, by changing silicates to clay and by slowly dissolving inert mineral particles, and to soften larger pebbles and grains.

As stated earlier, ceramic plants using surface clays were once widespread in Iowa, but advantages in the use of shale have led to the pre-emption of the field by larger plants that use shale. Shale occurs in much thicker deposits than desirable surface clays, is more uniform, handles better in pressing and drying, can generally be fired at a somewhat higher temperature, and produces a harder ware. Surface clays are at present being used in the manufacture of heavy clay products at Kimballton, Audubon County; Garrison, Benton County; Gladbrook, Tama County; and Winfield, Henry County.

The plant and pit of the Roxy Clay Works are located on the south side of the valley of Indian Creek, approximately three-quarters of a mile south of Kimballton, in the NE¼ SE¼ sec. 30, Sharon Township, (T. 79 N., R. 36 W.), Audubon County. The pit is being extended into a spur of the valley, into material most of which is loess, approximately 9 feet thick. The loess lowest on the slope, adjacent to and partly underlying a small draw, is stated to be fat and plastic; used alone it has high shrinkage and produces brittle ware. Loess from higher on the slope is too silty for a good product when used alone and is believed less weathered than that from lower down. Six feet of weathered glacial clay, separated from the overlying loess by a sharp irregular contact, is also used; this is red, sandy and pebbly, and grades to yellow below. The proportions of these three materials are varied in accordance with results secured in presses and kilns.

The plant and pit of the Garrison Brick and Tile Works are immediately south of Garrison on the north side of the wide terrace of Hinkle Creek in the NW¼ SE¼ sec. 29, Jackson Township, (T. 85 N., R. 11 W.), Benton County. The raw material is brown silty alluvium, somewhat loess-like in character, up to 6 feet thick, resting upon gravel. It is stated to be not as smooth or soapy as shale, and to tend to rub when scraped and to mold well. The kilns are burned at approximately 1700° F. with temperatures at the bottom as low as 1200° and as high as 1800° F. around the pockets. Several acres have been worked over in the winning of clay for this plant.

The plant and pit of the Gladbrook Brick and Tile Co. are on the south side of the valley of Wolf Creek, west of Gladbrook in the NE¼ sec. 8, Spring Creek Township, (T. 85 N., R. 16 W.), Tama County. The surface clay in this case also is a yellow loess somewhat reworked by slope wash and leaching. It is stripped of topsoil and then excavated to a depth of 6 feet. The unburned ware produced from clay is said to be very fragile and to crack and check easily in the dryer. The clay is also very sticky, so that it requires more power in handling than shale. The kiln temperature in firing the clay is 1900° F. Only bricks are made at this plant, as the clay cannot be very successfully used in the manufacture of drain and structural tile.

The Winfield Brick and Tile Co. with plant and pit southwest of Winfield on a tributary of Crooked Creek in the NE¼ sec. 16, Scott Township, (T. 73 N., R. 5 W.), Henry County, is using a surface clay to a depth of approximately 8 feet. The material is principally loess with possibly some weathered glacial clay. The loess has been weathered and reworked by fluvial erosion.

SHALES OF THE MAQUOKETA FORMATION

The Maquoketa is the lowest and oldest formation in Iowa which has recently been used in the manufacture of clay products. It has an approximate maximum thickness of 300 feet, and is described by Beyer and Williams[7] as consisting of "a series of beds, mainly shales, varying much in color, composition and texture." The lower part is described as made up of thin fissile shales, with some earthy, non-laminated beds carrying fossils. The upper portion consists of plastic clay shales carrying occasional indurated fossiliferous bands near the top and passes into thin layers of impure earthy dolomite. These dolomite layers are transitional to the thick-bedded Silurian limestone which lies above them. Most of the Maquoketa shale used recently in the ceramic plants is believed to have come from below the indurated fossil bands near the top of the formation.

This formation directly underlies the mantle in some part or parts of each of the following counties: Allamakee, Bremer, Clayton,

[7]Beyer, S. W. and Williams, I. A., The geology of clays: Iowa Geol. Survey, vol. 14, pp. 384-395, 1904.

Clinton, Delaware, Dubuque, Howard, Fayette, Jackson and Winneshiek. It is exposed in many places, and close to the surface in many more. It is overlain by the heavy-bedded Silurian limesone, which may be recognized by its buff color and tendency to form cliffs. Thus the steep slopes beneath the limestone ledges are underlain by the shale. A summary of the localities where these shales are or have been rather well exposed, according to Beyer and Williams[8], is given below:

Clayton County.
- Marion Township, in the NE¼ sec. 18, 1½ miles northeast of Elgin.
- Cass Township, 1½ miles northeast of Strawberry Point.
- Lodomillo Township, 1½ miles north of Edgewood; Bear Creek near Edgewood.
- Sperry Township, in the NE¼ sec. 33, on a tributary of Hewett Creek.

Clinton County.
- Numerous exposures in the northeastern part of the county.
- Spring Valley Township, northern limit of Lyons; in the bluffs along Mississippi River.
- Elk River Township, various places in the bluffs along Mississippi River.

Delaware County.
- Colony Township, along Little Turkey River and Elk Creek; sec. 3, the source of clay once used in a pottery at Colesburg.

Dubuque County.
- The northeast part of the county in general, and a small area in the northwest.
- Center Township, accessible at Kidder and Graf.
- Vernon Township, accessible at Peosta.

Fayette County.
- Clermont Township, bluff northeast of railway station at Clermont.

Winneshiek County.
- Many outcrops in the southeastern third of the county.
- Washington Township, in the SW¼ sec. 18; and in the SW¼ sec. 13.
- One mile northeast of Fort Atkinson.
- One and one-half miles southeast of Calmar.
- At intervals along Turkey River as far north as Spillville.

Three ceramic plants have until the last decade or so used Maquoketa shale as raw material.

The Bellevue Clay Products Co. has until recent years operated a brick and tile plant at Bellevue, Jackson County. The pit of the company, located on the east side of a small tributary to Mill Creek in the NE¼ sec. 19, Bellevue Township, (T. 85 N., R. 5 E.), exposed weathered Maquoketa shale, in two openings, for a distance of several rods, and to a height of approximately 25 feet. This was almost entirely a blue-gray argillaceous shale, weathered to clay. The bottom of the pit consisted of a layer of a few inches thick of hard, brown, ferruginous sandstone, with more argillaceous shale, essentially unweathered, below. Gypsum fragments, of the variety satin spar, were numerous on the weathered slopes. Any extension

[8]Op. cit., pp. 889-395.

of this pit would encounter thick overburden, as the present workings are at the bottom of the valley and the slopes are steep. Brick, tile and flower pots were made.

The brick and tile plant of the Clermont Brick and Sand Co. is located at Clermont in Fayette County. Shale is trucked (1935) from a pit situated west of Elgin on the north side of the road to West Union and on the north side of a small valley tributary to Otter Creek, in the SW¼ sec. 15, Pleasant Valley Township, (T. 94 N., R. 7 W.).

The pit face in 1935 was only a few rods wide, and material had been excavated a short distance into the steep hillside to a height of 18 feet. A foot or two of topsoil was removed and the underlying weathered shale, soft and plastic, was used in the plant at Clermont. The unweathered shale was gray brown, plastic when wet and slightly silty. The shale is overlain toward the top of the hill by the massive Silurian limestone which outcrops in thick ledges. It is obvious that this pit would soon encounter thick overburden, including the limestone, and would be difficult to operate.

The Postville Tile Works, which discontinued operations several years ago, also used Maquoketa shale as raw material in its plant as Postville. Surface clay, secured near the plant and believed to be of loessal origin, was also used.

The shale was hauled by railroad from a pit on the south side of the valley of Otter Creek in the SE¼ sec. 29, Pleasant Valley Township, (T. 94 N., R. 8 W.), Fayette County. The bottom of the pit was 20 feet above the base of the slope and the pit, which extended approximately 100 feet along the side of the valley, had a height of 20 feet. The material was entirely a blue, slightly silty shale, with a tendency toward fissility. The upper part, nearer the surface, was softened by weathering and stained brown. Here also ledges of Silurian limestone outcropped on the steep hillside above and it was apparent that extension of the pit into the side of the valley would soon encounter difficulty from this source.

The shale in these three pits is a uniform slightly silty material. Somewhat weathered shale near the surface was free of lime. Reasonably good ware could be made from the weathered shale, as demonstrated by the long operation of these and possibly other plants in the northeastern part of the State. Regardless of quality, the use of the Maquoketa shale is handicapped in many places by the presence of the thick ledges of Silurian limestone higher on the valley side. There are however considerable areas wherein the Maquoketa shale lies beneath gently rolling country, and from which the Silurian limestone is absent.

CLAYS OF THE NIAGARAN SERIES

The Niagaran series, although composed almost entirely of massive dolomitic limestone, has been shown to contain sporadic occurrences of high grade clay. These clays have been reported from Jackson, Clinton, Clayton and Linn Counties, which would place the deposits in the Hopkinton, the lower of the two formations comprising the series. They have not been used in the ceramic industry but would almost certainly find use if they were present in sufficient amounts. The deposits have been examined and the clays tested for ceramic properties by Galpin.[9]

Beds of the series in which these clays occur form the top of the bedrock beneath all or parts of Buchanan, Cedar, Clayton, Clinton, Delaware, Dubuque, Fayette, Jackson, Johnson, Jones, Linn, Muscatine, Scott and Winneshiek Counties. They contain, in addition to the massive dolomitic limestones, small thicknesses of calcareous shale. These shales are unsuited to ceramic uses because of their lime content.

The high grade clay to which reference has been made occurs as crevice and cavity fillings in the limestone, in bodies the dimensions of which are never more than a few or several feet in any direction. According to Galpin this clay consists of material which was originally part of the shale layers of the formation. The layers were leached of the lime content by ground water, and the residual material accumulated in openings thus created in the limestone and in widened joints. The clay is hard, earthy and light gray in color, and burns to a light buff at a relatively high temperature.

Galpin has reported the occurrence of this clay at the following localities:

Clinton County.
- Sec. 10, Deep Creek Township, 5 miles northeast of Goose Lake, on what is now the H. P. Heneke farm.

Jackson County.
- In the W½ sec. 35, Iowa Township, 4½ miles east of Miles, on what is now the Ernest Jepsen farm.

Small amounts of clay from these occurrences were shipped to ceramic plants for trial, but the deposits have not been developed further because of the limited size. Other deposits have been reported from elsewhere in Clinton and Jackson Counties, and some

[9] Op. cit., pp. 61-63.

have been reported to the writer from Clayton and Linn Counties. None of these is believed of commercial size. Other occurrences may be discovered, but unless they are in much larger deposits they are not likely to be exploited.

SHALES OF THE UPPER DEVONIAN SERIES

The Lime Creek and Sheffield formations of the Upper Devonian series contain shale suitable for the manufacture of ceramic products.

Juniper Hill member, Lime Creek formation. The Lime Creek is divided into three members.[10] The two higher, the Owen and the Cerro Gordo, total approximately 90 feet in thickness, and consist principally of limestone and calcareous shales. The Juniper Hill at the bottom is described by Stainbrook as "a homogeneous dark blue plastic shale, 90 to 100 feet thick and sparsely fossiliferous." Shale from the Juniper Hill member is used by the Mason City Brick and Tile Co. and by the Rockford Brick and Tile Co. for the manufacture of ceramic products. It is also used by the Northwestern States Portland Cement Co. and the Lehigh Portland Cement Co. as a source of the argillaceous material required in the manufacture of portland cement.

The Lime Creek formation forms the top of the bedrock of a broad belt which extends from southwestern Floyd County through Cerro Gordo, Winnebago and Hancock to eastern Kossuth County. The boundaries are not accurately known because of lack of outcrops and well records. The boundaries of the Juniper Hill member also are not known but the upper surface presumably forms the top of the bedrock of approximately the northern half of this belt over much of the distance. It should therefore be present beneath the mantle in approximately the area of the counties and townships of table 2. The mantle is thick in most of the area, and this, together with the nature of the material, leads to scarcity of outcrops. The formation furthermore varies somewhat in character, so one cannot be very certain of the extent of material suitable for ceramic purposes.

At Mason City the most complete and informative section is the pit of the Mason City Brick and Tile Company in the southwestern part of the city in sec. 17, Mason Township, (T. 96 N., R. 20 W.). A heavy clay products industry has been operated in this vicinity for

[10]Stainbrook, M. A., Stratigraphy of the Devonian system of the upper Mississippi Valley: Kansas Geol. Soc. Guidebook 9th Ann. Field Conf., pp. 256-258, 1935.

many years by various companies and a considerable area of ground has been worked over in the winning of the clay. The section differs somewhat from place to place, due not so much to changes in the character of the shale formation as to the relief of the bedrock surface, the dip of the strata, and the depth of weathering.

TABLE 2

Approximate Distribution of the Juniper Hill Member by Counties and Townships

Kossuth County
- Southern two-thirds of German.
- Northern half of Buffalo.

Winnebago County
- Southern two-thirds of Grant.
- Southern two-thirds of Linden.
- Southern half of Forest.
- Southern third of Mount Valley.

Hancock County
- Northern half of Bingham.
- All except southwestern sixth of Crystal.
- All of Madison and Ellington.
- Northeastern corner of Britt.
- Northern half of Garfield.
- Northern half of Concord.

Cerro Gordo County
- All except northeastern corner of Grant.
- Southwestern corner of Lincoln.
- Northern two-thirds of Clear Lake.
- All of Lake and Owen.
- Southern two-thirds of Mason.
- Northeastern third of Mount Vernon.
- Northern two-thirds of Bath.
- Northeastern third of Dougherty.

Floyd County
- Western half of Rockford.
- Northwestern quarter of Scott.

The section exposed by operations in 1932 is described below:

Section: Mason City Brick and Tile Company, Mason City, Cerro Gordo County, 1932

Member	Description	Thickness Feet	Thickness Inches
5	Weathered glacial till	0-2	
4	Clay, yellow in color and evidently derived from beds containing limestone, as it contains many limestone fragments much softened by weathering	4	8
3	Shale, silty, yellow brown as a result of weathering (T)[11]	3	
2	Shale, silty, blue gray, very plastic when wet, contains three layers of calcareous fine-grained sandstone up to 18 inches in thickness. (T)	7-9	
1	Shale, silty, blue gray, plastic when wet, only vaguely stratified; contains more silt or sand in the lower part. (T)	21	6

[11]Ceramic tests were made on a sample from this member and from all others marked "(T)". Results of tests are given in the section Tests on Iowa Shales and Clays.

Members 4 and 5 constituted the overburden at that time. The shale from member 2 could not be salvaged and the entire thickness of this member was therefore discarded and piled back in the pit. Members 1 and 3 were being used in the proportion of eight to one.

By 1942 the workings had been extended several hundred feet approximately southeast of the site of the section already described. The section, described below, was much like the one exposed 10 years earlier.

Section: Mason City Brick and Tile Company, Mason City, Cerro Gordo County, 1942

Member	Description	Thickness Feet	Inches
4	Clay, sandy, yellow, derived from weathering of thin drift.		4
3	Weathered drift and limestone, brown; contains much soft crumbly limestone, much clay and silt admixed.	6	
2	Shale, dark blue gray and plastic when wet, silty, contains three beds of calcareous siltstone or fine-grained sandstone up to approximately 1 foot in thickness.	10-12	
1	Shale, dark blue gray and plastic when wet, silty, very compact.	30-35	

Members 1 and 3 are used in the manufacture of the ceramic ware. Members 2 and 4 are waste. Member 1 is so hard that blasting is employed to break it down. This material is described[12] as quite plastic. When mixed with water to the right consistency it becomes quite slippery. It goes through the auger machine and dries very easily as compared to most clays. After forming, the pieces are easily handled without deforming and dry easily without cracking. The clay forms a dense red-brown body when fired from 1900° to 2000° F. At temperatures above 2000° F., it is apt to deform or melt. Little or no difference in the properties of the shale throughout the section has been found.

Extensive workings at this locality with a large amount of material removed has resulted due to the large industry which has existed in the vicinity. There were at one time seven ceramic plants, whereas there are now (1942) but four in condition to operate, all under one ownership and securing shale from the one pit described above.

The pit in the Juniper Hill member from which the Northwestern States Portland Cement Co.[9] secures its argillaceous material (T) is located in sec. 5, Lime Creek Township, in the western part of Mason City, and north of the pit of the Mason City Brick and Tile Co. The shale was formerly removed by harrowing and dragging,

[12]Orally by Mr. Howard Lewis, Ceramic Engineer, Mason City Brick and Tile Co.

and the surface thus exposed was one of plastic silty clay, very light gray on the surface where it had been allowed to dry, but blue gray beneath. It contained abundant gypsum crystals, found lying on the surface. The floor of the present pit, lying approximately 20 feet below the original surface, is of similar material. The working face, from which material is at present (1942) being removed by shovel operations, is made up of 5 feet of gray-buff silty shale overlain by 3 feet of gray silty shale. The difference in color may be due to the water-soaked condition of the lower part, since it probably has been covered with water when the pumps were not working and the pit was flooded.

Analyses of shale from this pit have been furnished by the Northwestern States Portland Cement Co. and are included in the section discussing chemical analyses of Iowa shales and clays.

The shale from the Juniper Hill member is also used by the Lehigh Portland Cement Co. located in the northern part of Mason City. The pit is west of the plant in sec. 32, Lime Creek Township, and the material exposed is much like that described in the foregoing.

These two companies have removed great quantities of shale from extensive acreages in the course of their operations. This may be judged from the fact that the annual capacity of the Northwestern States Portland Cement Co. is 2,000,000 barrels of cement and that of the Lehigh Portland Cement Co. is 1,750,000; 25 percent shale is used in the raw material or approximately 140 pounds per barrel of cement.

Shale from the Juniper Hill member is also used in the manufacture of heavy clay products by the Rockford Brick and Tile Co. The plant and pit are located southwest of Rockford, Floyd County, on the south side of the valley of Clay Bank Creek in the NE¼ sec. 16, Rockford Township. (Fig. 1).

Section: Rockford Brick and Tile Co.,
Rockford, Floyd County.

Member	Description	Thickness Feet
4	Till, intermingled with weathered shaly limestone below, yellow and buff in color, very fossiliferous in places, constitutes overburden	up to 15
3	Shale, blue gray, plastic when wet, silty	5-8
2	Sandstone, fine-grained, or siltstone, slightly calcareous, poorly cemented, stained irregularly brown with limonite where overlying material is thin and water permeates, forms waste, at least where well-cemented.	1-2
1	Shale, blue gray, plastic when wet, silty, with some horizons a foot or more thick containing larger amount of silt. (T)	25

Figure 1. Shale pit of the Rockford Brick and Tile Company, Rockford, Floyd County.

The highly fossiliferous weathered limestone which forms much of the overburden is believed to be the base of the overlying Cerro Gordo member of the Lime Creek formation. The bulk of the material in this section is much like that of the sections exposed at Mason City. It has here, as there, the advantage from the viewpoint of the heavy clay products manufacturer of being rather uniform in composition. The content of calcite is apparently not great enough to be a detriment.

The Sheffield formation. The Sheffield is believed to form the surface bedrock of a belt extending from western Johnson County northwest through Iowa, Benton, Tama, Grundy, Butler, Franklin and Cerro Gordo to southeastern Hancock County. Stainbrook describes the formation as "predominately shale, soft, blue to gray in color, sparsely fossiliferous in the lower part, with thin intercalated layers of brown dolomite. The upper portion is mostly dolomite, brownish in color, more or less massively bedded with subordinate green and brown shales and thinly bedded gray limestone."

Shale from this formation is used by the Sheffield Brick and Tile Co., Sheffield, in the manufacture of heavy clay products. That which is used is evidently from the lower part of the formation and presumably should form the surface bedrock of a belt underlying the counties and townships listed in table 3. Because of the cover of mantle and the character of the material which would tend to make it break down in outcrop, the exact extent of the shale beds is not known. It should be recognized also that the character of the material may differ along the strike of the beds, so that the horizon occupied by satisfactory shale at Hampton may contain a more limy shale or shaly limestone at points some distance away along the strike of the formation.

The only company using shale of the Sheffield formation is the Sheffield Brick and Tile Co., located south of Sheffield, Franklin

TABLE 3

Approximate Distribution of the Sheffield Formation by Counties and Townships

Hancock County
- Sections 8, 9, 10, 11, 12, 16, 17, 18, of Avery.

Cerro Gordo County
- Middle third, trending southeast of Grimes.
- Southern third of Pleasant Valley.
- Southern quarter of Geneseo.
- Southern fifth of Dougherty.

Franklin County
- Northeastern corner of Ross.
- Northeastern two-thirds of Westfork.
- Eastern quarter of Ingham.

Butler County
- Western quarter of Bennezette.
- Western third of Pittsford.
- One-third of Madison; a strip trending southeast from the northwest corner.
- Southwestern third of Ripley.
- Northeastern half of Monroe.
- Southwestern third of Albion.

Grundy County
- Beaver, exclusive of northeastern and southwestern corners.
- Eastern two-thirds of Lincoln.
- Southwestern third of Grant.
- Northwestern quarter of Washnigton.
- Black Hawk, with the exception of the Northeastern quarter.

Tama County
- Northeastern half of Grant.
- Southwestern two-thirds of Buckingham.
- Northeastern half of Perry.
- Clark, with the exception of the northeastern quarter.
- Northeastern half of Oneida.

Benton County
- Southwestern quarter of Monroe.
- Western half of Homer.
- Kane, approximately half, from northwest to southeast.
- Northeastern fifth of Iowa.
- Southwestern fifth of Union.
- Southwestern two-thirds of Leroy.
- Southwestern sixth of St. Clair.

Iowa County
- Northeastern quarter of Marengo.
- Northern half, exclusive of northeast corner, of Washington.
- Southern half of Lenox.
- Northeastern quarter of Iowa.

Johnson County
- Small area, southwestern corner of Monroe.
- Northwestern quarter of Oxford.

County, on the south side of the valley of Bailey Creek in the NW¼ sec. 9, Ross Township (T. 93 N., R. 20 W.). The shale pit is north of the plant; it has been extended west to the point where the thick drift overburden is becoming a problem.

Section: Sheffield Brick and Tile Co.,
Sheffield, Franklin County.

Member	Description	Thickness Feet	Thickness Inches
4	Drift, chiefly till, weathered, a few feet of top soil	3	10
3	Shale, blue gray to brown where stained with limonite, silty, somewhat calcareous, contains slightly calcareous fine-grained sandstone or siltstone, brown with weathering on joint faces at least, up to 4 inches thick	10	11
2	Sandstone, fine-grained, or siltstone, hard, noncalcareous, weathers buff, joint surfaces dark brown		4
1	Shale, dark gray where wet, but dries to light gray, silty, plastic. (T)	23	

Only member 1 is used as raw material. The number of siltstone beds has increased as the pit has been extented west. This is due to the section getting higher.

Summary. From the foregoing it is apparent that the shales of the Sheffield formation and of the Juniper Hill member of the Lime Creek formation as used by the ceramic plants at Mason City, Rockford and Sheffield and by the cement plants at Mason City, are much alike. In each case the material is a gray-blue, silty shale, in places somewhat calcareous unless leached by weathering.

Horizons or beds of more sandy or silty material are also present in these sections and some of them are cemented with more calcite.

The shale from any one of these pits is quite uniform, which should be an asset in its use. Those of the Des Moines series, the next to be considered, may show considerable variation, at least in color, in a single pit. The ceramic ware made from these Devonian shales is obviously a satisfactory product. The tests made upon them confirm their suitability for the manufacture of heavy clay products, but do not suggest possibility of their use in higher grade products such as pottery or refractory ware.

SHALES AND CLAYS OF THE DES MOINES SERIES

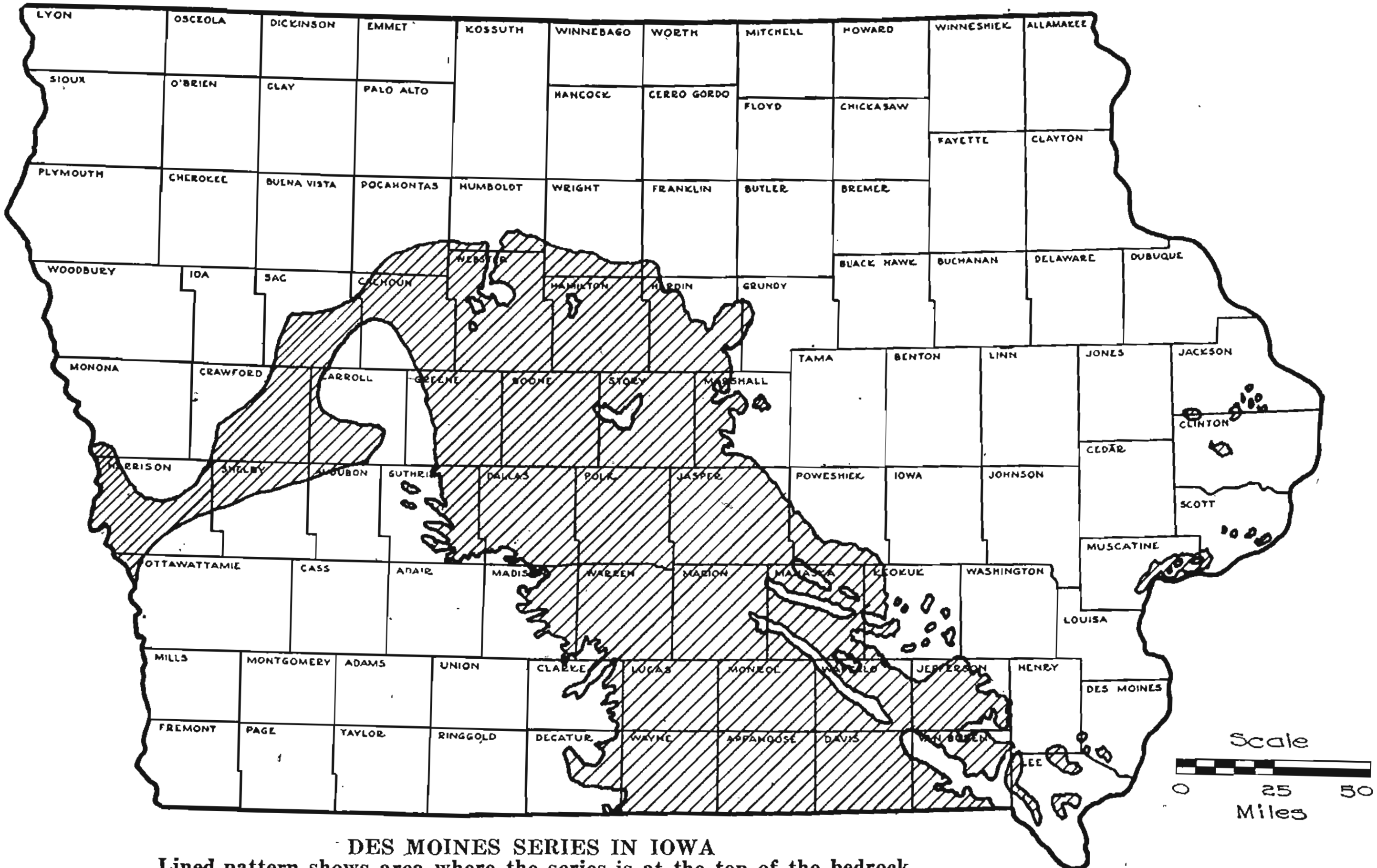
Introduction. The shales and clays of the Des Moines series constitute a raw material resource of great value. They form the surface bedrock of an area of many thousand square miles and are accessible at many places. Some of the largest heavy clay products plants of the State secure their raw material from this series.

Extent. The series forms the top of the bedrock over a large area, extending as a broad curving band (pl. 2) northwestward from Pottawattamie and Harrison to southern Humboldt County, and thence southeastward to the southern boundary of the State in Wayne, Appanoose, Davis and Van Buren Counties. It covers all or practically all of Dallas, Polk, Lucas, Jasper, Monroe, Wayne, and Appanoose; more than approximately half of Harrison, Shelby, Carroll, Crawford, Sac, Calhoun, Hardin, Story, Boone, Greene, Webster, Warren, Marion, Mahaska, Wapello, Jefferson and Van Buren; and less than approximately half of Pottawattamie, Wright, Audubon, Pocahontas, Humboldt, Franklin, Grundy, Guthrie, Poweshiek, Madison and Keokuk Counties. From the presence of scattered outliers northeast of the main belt in Lee, Des Moines, Henry, Louisa, Washington, Johnson, Muscatine, Clinton, Scott and Jackson Counties, it is known that this series at one time extended far to the east of its present boundaries, and was continuous with the Pennsylvanian formations of Illinois.

Structure and relations. The direction of dip of the beds of the series varies, depending upon the position of the locality with respect to the periphery of the structural basin of which they are a part. They dip approximately south in the northern part, southwest and west on the east side, and southeast and east on the west side. The axis of the basin trends approximately S. 25 W. from the vicinity of Fort Dodge. Dips are generally low, of the order of 10 feet per mile. There frequently are reversals of these regional dips. Faults of small magnitude are also present.

In the central part of the basin, away from the area of outcrop, the Des Moines is covered by the Missouri series of the Pennsylvanian system, by Cretaceous beds, or both. The thickness of surface materials, glacial drift, loess, alluvium, and residual mantle ranges up to a few hundred feet, and varies greatly from place to place. Some counties have very few or no outcrops and in others they are abundant.

Thickness and stratigraphy. The Des Moines series has a maxi-



DES MOINES SERIES IN IOWA
Lined pattern shows area where the series is at the top of the bedrock.

mum thickness of approximately 750 feet, a large proportion of which is shale, with lesser amounts of clay or underclay, sandstone, limestone, conglomerate and coal. Most of the shale is silty, some of it so much so that it might more properly be called siltstone. Such material will however be called shale in this report, since it is generally not discriminated as siltstone by ceramic manufacturers. Some of the shales are sandy, some calcareous or limy and others carbonaceous. Calcareous and carbonaceous shales are less desirable for ceramic purposes than the shales in which they are lacking.

Beds of these different kinds of shale occur interstratified with other rocks and in the upper part of the series the same succession is repeated many times. Such a succession of beds, called a cyclothem, has sandstone at its base and, in order above, silty shale or siltstone, underclay, coal, carbonaceous shale, silty shale, limestone and silty shale. An individual cyclothem may have a thickness of scores of feet.

The individual beds of the series vary greatly in thickness. In places, as at the Ledges State Park, beds of sandstone are approximately 100 feet thick, but this is extreme. Some of the beds are sharply set off from one another; others grade vertically or laterally from one kind of rock to another. Some of the beds have only limited areal extent and others extend over large areas.

Shale. Most of the shale members of the Des Moines series are some shade of gray in color, many others are maroon and there are others that are various shades of red, brown and yellow. Many of the beds are not of a solid color, but are banded, streaked or mottled. The various shades of red, brown and yellow are due to the presence of iron oxide minerals, usually hydrated, where the iron is in the ferric state; although the iron content of these shales may be no higher than that of the gray shales. These oxidized and hydrated iron-containing minerals may be original, or they may be secondary, formed as a result of the action of oxidizing ground waters upon the shales subsequent to their deposition. A similar change of color upon oxidation is quite apparent in the glacial clays of the mantle; deep road and stream cuts grade from a blue gray, the original color of the glacial clay, upward to some shade of brown at the top.

Calcareous or limy shales, less common in the Des Moines series, have a content of the mineral calcite. The calcite may have been originally present in the sediment, or it may have been brought in by ground water and precipitated. In some places calcareous and ferruginous or iron-containing nodules of various shapes are formed in the shale by this precipitating action of ground water. Such masses known as concretions are obviously undesirable in commercial shale since they are difficult to crush fine, and the particles burn to free lime.

The carbonaceous shales contain carbonized remains of plants which accumulated with the mud or clay. Accumulation of plant material alone leads to the formation of peat and subsequently coal. A carbonaceous shale will often be found to grade laterally into coal or to lie above it.

Underclay. Coal and coal horizons are usually underlain by clay of variable thickness known as underclay. This clay usually is more refractory than the shale of the series and ranks as fire clay. Fire clay of the best quality is not believed present in any quantity in the Des Moines series in Iowa. In many parts of the United States, particularly in the coal fields east of Iowa, the clays beneath the coal are notably more refractory than the great body of shales of the series. They burn only at high temperatures, and the products made from them will resist a high degree of heat, and so can be used in furnace linings and crucibles. The products are also generally white or light buff in color. The unusual character of these fire clays is largely due to the lack or low content of fluxing and coloring oxides such as those of potassium, sodium, magnesium, calcium and iron. These constituents are believed to have been removed from the clays during the growth of the coal-making plants above them. Fire clays in commercial thicknesses, suitable for use in refractories, have not yet been found in Iowa. Most of the underclays of Iowa contain finely divided pyrite which produces brown or "iron" spots of low melting point in the product. Some of them, however, have proven suitable for the manufacture of buff brick, but the deposits are not very thick.

Overburden and outcrops. The thickness of the mantle directly overlying the Des Moines series ranges, as it does over the bedrock of the entire State, to as much as a few hundred feet. It is thickest in the area of the Mankato or youngest drift, which extends from the city of Des Moines north to the northern boundary of the State, where it has a width of several counties. Many of the counties in this area have no outcrops of the consolidated rock beds, others have but few where the mantle is thin. Outcrops and places of thin mantle are along the sides of steep, sharply incised valleys.

Outside of the area of Mankato drift the overlying mantle is on the whole thinner, but even here there are large areas without outcrops of indurated materials. Areas with valley systems well developed may have numerous outcrops along the sides of the valleys.

Because so much of the Des Moines series is shale, outcrops and man-made exposures are likely to become covered relatively quickly by slope wash and vegetation, since the shale softens so easily upon weathering. The outcrops are therefore lacking unless steepened and renewed by stream cutting. The limestone and sandstone beds interstratified with the shales are somewhat more resistant to weathering and erosion, and may persist in outcrop. Their presence may thus serve as a guide to overlying or underlying shales or clays which are covered by mantle. Localities having the thick channel sandstones are, however, to be avoided, since they cut irregularly into the shales and attain a thickness of scores of feet.

Bedrock shale and clay pits are comomnly located on the sides of valleys not only in the Des Moines series, but elsewhere. There the mantle is thinnest, therefore the cost of extracting the clay is less because of the smaller amount of overburden to be moved. As the pit is extended into the side of the valley, the thickness of mantle mounts rapidly if the valley is steep-sided, and experience has shown that much difficulty may be experienced if the mantle is waste material, particularly glacial clay, that must be removed.

It is also a matter of common observation that the shale near the surface on the side of a valley has been considerably affected by weathering. It has been softened, leached and somewhat oxidized. As the pit is extended into the valley side, and the distance from the surface becomes greater, the shale is less affected by weathering. The ceramic character of a particular horizon thus changes as the pit is extended, a matter which may lead to difficulty in the treatment of the material unless it is well understood.

The distribution of the Des Moines series in the counties where it occurs, its characteristics, the extent to which it is used and related matters are described in the following pages. County reports of the Iowa Geological Survey dealing with the geology of the respective counties will be cited in cases where they contain information on the series.

Appanoose.[13] The beds of the Des Moines series form the top of the bedrock throughout Appanoose County. The mantle ranges up to 150 feet beneath the divide areas but is thin or absent in many places along the deeper and larger valleys, as along Chariton River, Walnut Creek, Buck Creek, Shoal Creek, Cooper Creek and their

[13]Bain, H. F., Geology of Appanoose County: Iowa Geol. Survey, vol. 5, pp. 374-397, 1896.

larger tributaries. The character of the beds making up the upper part of the series in the county is well known from natural and artificial outcrops, coal mining records and operations, and the shale pit of the Centerville Clay Products Company. Extensive mining of the well-known Mystic coal has contributed much information regarding the stratigraphy of the series. In addition to the coal, the series contains much shale and underclay, thick and persistent limestone members, and conglomerate.

The shales and clays have been used in the manufacture of heavy clay products at Centerville for approximately 40 years, but so far as is known have not been used elsewhere in the county. The plant of the Centerville Clay Products Company is located on the north side of a small tributary of Manson Creek immediately south of Centerville in the NW¼ sec. 1, Vermillion Township, (T. 68 N., R. 18 W.). Shale has been secured from an opening in the valley side east of the plant and the present operation is in the south end of this pit.

Section: Centerville Clay Products Company;
Centerville, Appanoose County.

Member	Description	Thickness Feet	Thickness Inches
6	Loess, highly oxidized at base	7	
5	Peat.		6
4	Shale, dull yellow-brown, slightly silty, lacks definite stratification, probably a weathered phase of underlying material, contains clay ironstone concretions up to 3 feet in diameter	20	
3	Shale, blue gray, slightly silty, micaceous, has tendency to fracture in flattened nodules approximately 1 foot in diameter, lower part has prominent vertical and curved joints, contains cigar-shaped pyrite concretions and clay ironstone concretions. (T)	26	
2	Shale, dark gray, silty. (T)	4	
1	Limestone		8

In older parts of the pit carbonaceous shale and fossiliferous limestone lie above member 4 of the above section.

The section is notable among those in shale pits of the Des Moines series in that it is essentially uniform for the entire thickness of 50 feet, except for a slight variation in amount of silt and the weathering of the upper part of the section; uniformity of color of the unweathered shale is conspicuous. The entire section, exclusive of 6 inches of topsoil and the clay ironstone concretions, has been used in the manufacturing process, and suitability of the materials thus made apparent. Variation in the behavior of the material from the various members has been observed, members 3 and 6 being considered notably plastic and member 4 rather short.

Audubon. Boundaries of the area directly underlain by the Des Moines series in Audubon County are not accurately known. The beds are believed to form the top of the bedrock of an area of many square miles in the northwestern part, in northern Lincoln and northwestern Cameron Township. Elsewhere they are overlain by younger sedimentary rocks. They are not exposed in the area where they form the top of the bedrock because of the thick drift mantle and the lack of deep valleys.

Thickness of the series in this area is presumably not more than a few score feet. Shale and clay are undoubtedly present as in other counties where the series is present but they are hardly of even potential value, because of the generally thick overburden.

Boone.[14] Beds of the Des Moines series form the surface bedrock of the entire county except for an area of 1 or 2 square miles in eastern Jackson Township. They are exposed or covered with only thin mantle in many places along the Des Moines River and to some extent along the lower parts only of its deeper tributaries. Elsewhere they lie beneath drift that may average more than 100 feet in thickness. Much information regarding them has been gained from coal borings and shafts.

Shales and clays suitable for the manufacture of ceramic products are believed numerous in the section; coal, limestone and sandstone are other constituents. A channel sandstone up to 80 feet thick forms the top of the section along the Des Moines River in Worth and Clay Townships. Shales and clays from the series were used in a plant at Logansport as recently as 1927. The pit located west of the plant on the east side of the valley of Des Moines River in the NE¼ sec. 24, Des Moines Township (T. 84 N., R. 27 W.) eventually encountered excessive overburden. Beyer has described the following section from this locality:

Member	Description	Thickness Feet	Inches
8	Drift and talus, varying in thickness, average for pit at the present time. (1903)	5	
7	Shale, variegated, gypseous, much weathered and shrinks considerably during drying and burning.	15	
6	Shale, gray blue, arenaceous below, in places a hard ledge appears and must be wasted.	4	
5	Shale, purplish, variegated, somewhat fissile	4	
4	Sandstone, argillaceous in part, hard ledge appears in places	4	
3	Shale, dense, gray blue to deep blue, but slightly fissile, the most important bed in the pit	14	
2	Shale, bluish gray, weathers almost white, finely arenaceous, massive	4	
1	Shale, dark blue to bluish black, gypseous.		

[14]Beyer, S. W., Geology of Boone County: Iowa Geol. Survey, vol. 5, pp. 184-201, 1896.

Calhoun. The Des Moines series is thought to underlie all of Calhoun County with the exception of the northwestern half of Williams Township. It is at the top of the bedrock beneath this area with the exception of that part overlain by younger sedimentary rocks; this includes townships as follows:

All of Jackson and Calhoun.
All except the northern fifth of Elm Grove.
The southwestern third of Twin Lakes.
The western third of Union.

Presumably it contains ceramic shales and clays similar to those in adjacent Webster County. They are believed to be without potential value because of the general thickness of overlying mantle and the absence of deep valleys on the sides of which the mantle might be thin.

Carroll. The Des Moines series is believed to underlie the entire county and to form the top of the bedrock throughout except in southwestern and western townships where it is overlain by Cretaceous beds, the boundaries of which are not certainly known. There are no outcrops and little is known of the series from well records, but it almost certainly contains ceramic shales and clays as it does in nearby Boone, Webster and Dallas Counties. These are also believed to lack potential value as a resource because of the generally thick mantle of glacial drift and the absence of deep valleys.

Clinton. Relatively small outliers or parts of outliers of the Des Moines series, none more than a few square miles in extent, in southwestern Welton, northern Bloomfield, and northern Sharon Townships, consist principally of sandstone. Shale and underclay are also present, but not believed to be thick enough to constitute a potential clay resource.

Crawford. Beds of the Des Moines series form the top of the bedrock beneath all of Crawford County with the exception of the northwestern townships. Boundaries are not definitely known. The beds are everywhere beneath drift averaging 100 feet or more in thickness, and while ceramic shales and clays are presumably present as in other counties, they have no potential value because of the heavy drift cover.

Dallas. Beds of the Des Moines series form the surface bedrock beneath the entire county with the exception of small areas in the southwestern corner, including the approximate south half of Union and the southwest quarter of Adams Townships. The mantle cover is thin and outcrops present in many places along the deeper valleys, the Des Moines River in Des Moines Township, the Middle Raccoon River in Linn and Union, the South Raccoon in Union, Adams, Van Meter and Boone Townships, and the lower parts of some of the deeper tributaries to these streams. The character of the beds is known from these outcrops, from the exposures at the shale pits at Adel and Redfield and from coal mining records and operations. Shale and clay are notably abundant in the upper part of the series as represented in the county, although there are also coals and thin limestones, as well as thick sandstones in some places, as along the west side of the Raccoon River at Redfield. Underclays which have the quality of a low grade fire clay are as elsewhere associated with the coal horizons.

The shales and clays have been used in the manufacture of heavy clay products at Adel, Redfield, Van Meter and De Soto. Three plants are at present operating, one at Redfield, one approximately a mile east, and one at Adel.

The sections at these shale pits are believed characteristic of the upper part of the series as it is represented in the southern part of the county. That of the Goodwin Brick and Tile Company (fig. 2) on the east side of the Middle Raccoon River Valley immediately

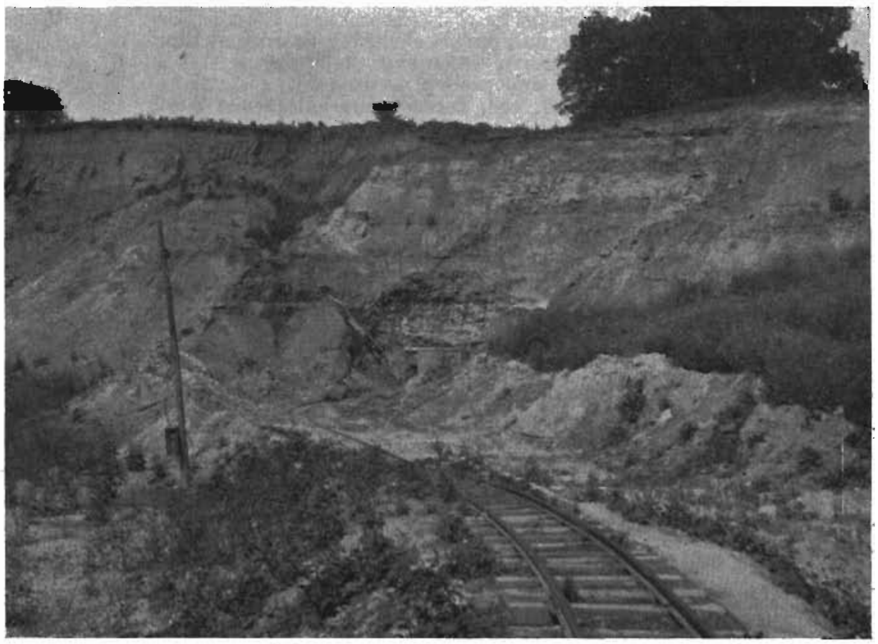


Figure 2. Shale pit of the Goodwin Brick and Tile Company, Redfield, Dallas County.

west of Redfield in the NW¼ sec. 5, Union Township, (T. 78 N., R. 29 W.), is the thickest.

Section: Goodwin Brick and Tile Company,
Redfield, Dallas County.

Member	Description	Thickness Feet	Thickness Inches
23	Loess.	0-5	
22	Sandstone, brown, cross-bedded, poorly cemented, contains carbonized plant fragments and pieces of shale near base, channel type cuts down into member 4 in north end of pit.	0-50	
21	Shale, silty, carbonaceous.	3	
20	Sandstone, buff, possibly part of channel sandstone.	1	
19	Coal and carbonaceous shale.	1	
18	Shale, gray, with 1 foot of possible underclay at top.	8	
17	Shale, gray and red, rather fissile, weathered	3	
16	Clay (underclay?), silty, mottled, purple and gray, angular fracture, weathered, resembles an underclay.	4	
15	Sandstone, buff to red, calcareous, soft, weathered and friable	1	4
14	Shale, variegated, dull purple and yellow, irregular fracture, weathered.	2	
13	Siltsone, gray, friable, nodular		6
12	Shale, fissile toward bottom, sandy toward top, weathered, variegated, gray, green, yellow	3	
11	Shale, gray, argillaceous, hard, resists weathering and forms a prominent band on face of pit.	1	
10	Shale, carbonaceous.		½
9	Shale, variegated, dull purple changing to gray at top, silty, starchy fracture, resembles underclay	6	
8	Shale, silty, gray and yellow, weathered	1	6
7	Shale, argillaceous, red, ferruginous calcareous concretions.	4	
6	Siltstone, greenish gray	8	
5	Shale, argillaceous, gray and red banded	3	
4	Limestone, lower 5 inches shaly, with undulating bedding, upper 3 inches weathers brown, impure	1	
3	Shale, carbonaceous, contorted, silty, carbonaceous film at base.		4
2	Clay, (underclay), silty, mottled purple and brown. (T)	5	
1	Shale, red and gray	5	

Members 14 to 21 inclusive as exposed in 1942, were all more or less affected by oxidation and solution, causing them to be stained and softened to a varying degree. The material was being taken from the south end of the pit (fig. 3) where the channel sandstone (member 22) was absent, and the entire thickness described above, with the exception of member 4 and calcareous concretions of member 7, was being used. A uniform mix, changing in its ceramic properties only very slowly and over a long period of time, was being obtained by the use of a planer. The relations in this pit are unusual due to the presence of the channel sandstone of varying

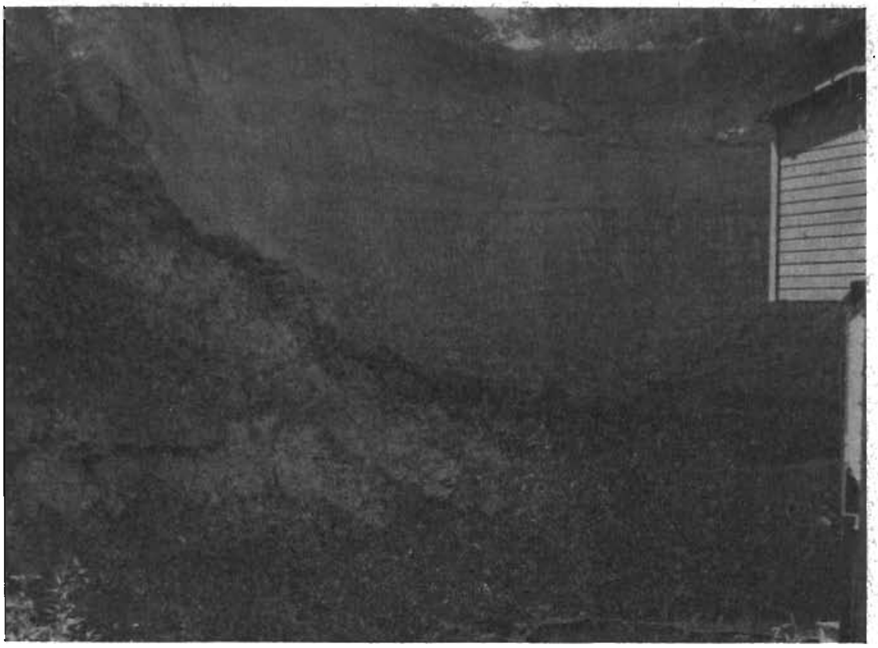


Figure 3. Channel sandstone at the pit of the Goodwin Brick and Tile Company, Redfield, Dallas County.

thickness, (fig. 4) and to the presence of at least one fault which cuts the pit, with downthrow to the north.

The pit of the Adel Clay Products Company (figs. 5 and 6) is approximately a mile east of that of the Goodwin Brick and Tile Company described above, and three-quarters of a mile east of the village of Redfield. It is also approximately one-half mile north of the plant, on the north side of the valley of Raccoon River in the NW¼ sec. 3, Union Township, (T. 78 N., R. 29 W.).

Section: Adel Clay Products Company,
Redfield, Dallas County.

Member	Description	Thickness Feet	Inches
8	Drift.	1-15	
7	Clay (underclay), weathered	2	
6	Shale, argillaceous, deep maroon throughout	4	
5	Shale, silty, laminated red and gray, a pronounced red zone approximately in the middle. (T)	12	
4	Shale, gray, carboneceous, with member 3 resists weathering better than 2, and projects from part of pit face not in use. (T)		4
3	Sandstone, soft, carbonaceous		2

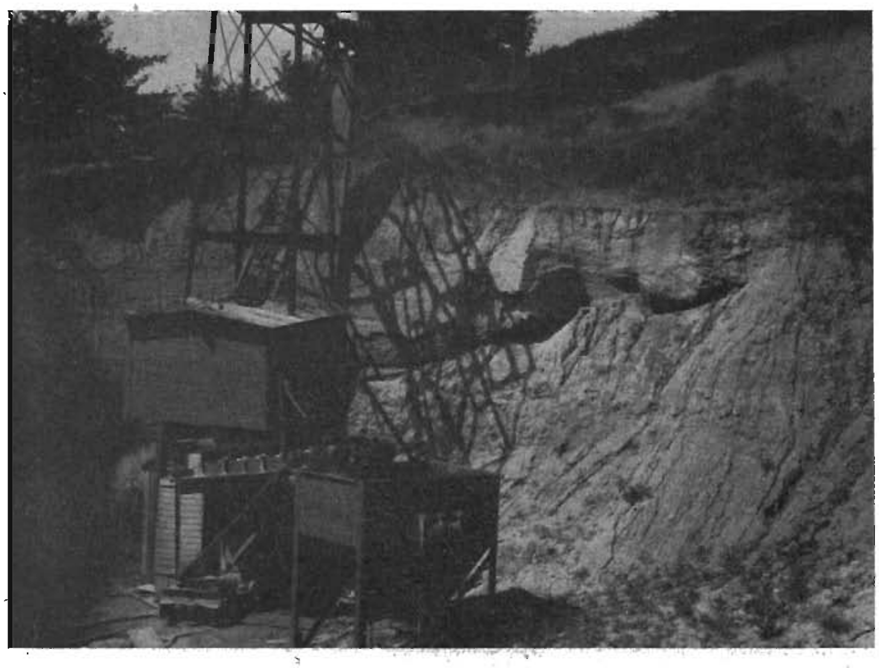


Figure 4. Channel sandstone at the pit of the Goodwin Brick and Tile Company, Redfield, Dallas County. This view is adjacent to that of fig. 3.

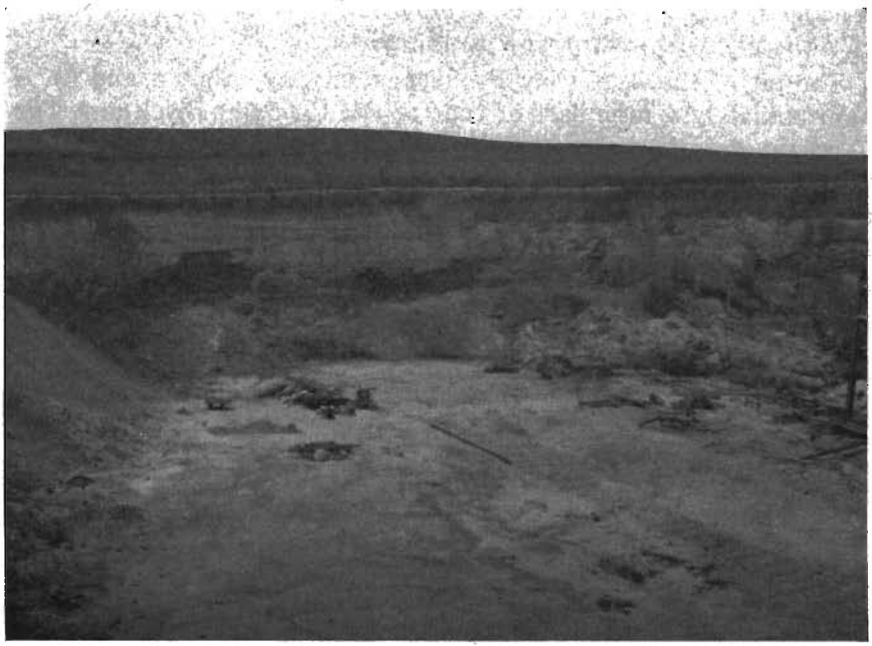


Figure 5. General view north of planer in the shale pit of the Adel Clay Products Company, east of Redfield, Dallas County.

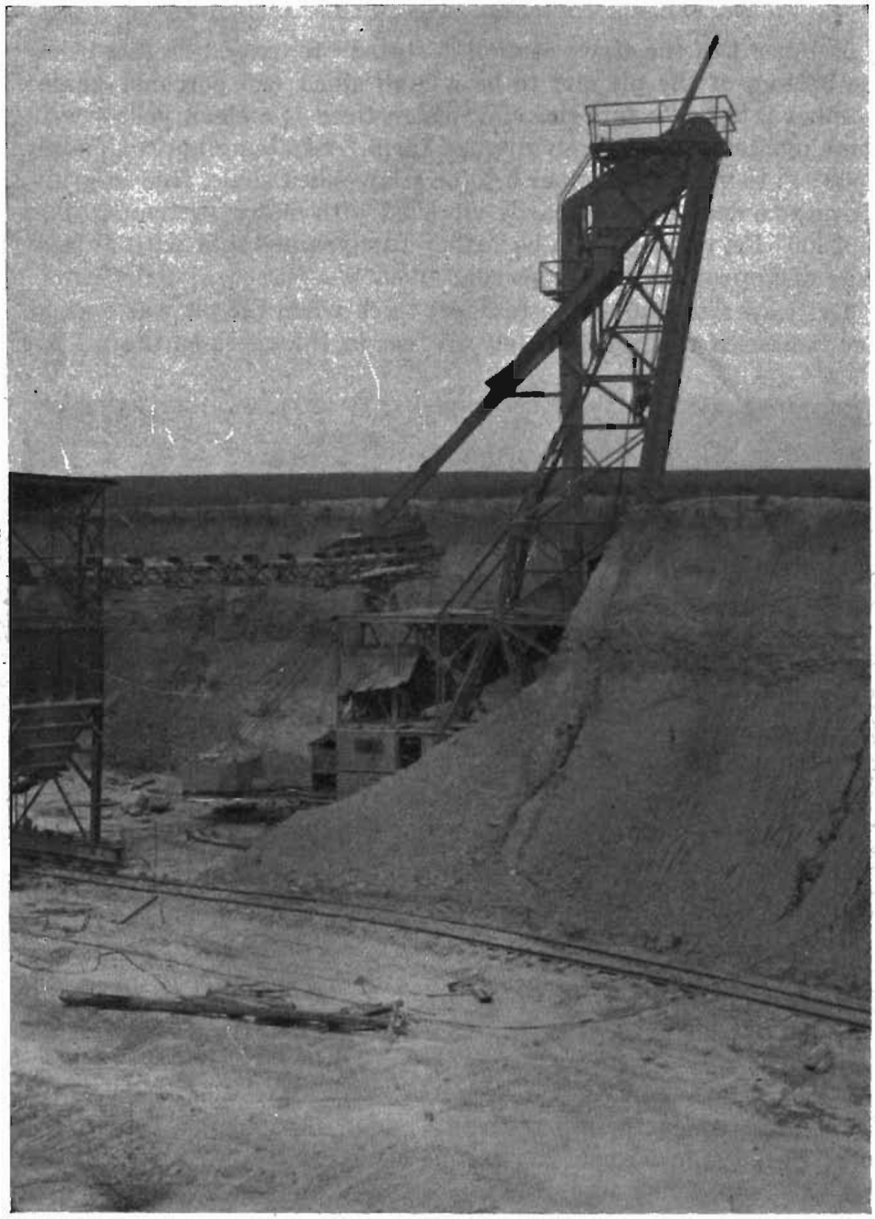


Figure 6. Shale pit of the Adel Clay Products Company, east of Redfield, Dallas County, with planer in position against the shale deposit.

2	Clay, variegated, purplish, angular fracture, has character of underclay, grades to shale below. (T)....	4
1	Shale, high in silt, greenish gray, splotched with red. (T)	12

Member 1 of the above section is stated[15] to extend 28 feet below the bottom of the pit and to be a high silica (80 percent) shale; member 2 to be "a fair fire clay which fired is a clean yellow with some pyrites in it in finely divided form," requiring approximately 2400° F. to vitrify; member 5 to be a low-silica shale, fine in grain, firing to a deep red, and easily vitrified with maturing temperature of 1600° F.; member 4 to be rather fine-grained and with an average of approximately 65 percent silica.

Drift overburden, only a few feet thick when the pit was opened, has increased to approximately 15 feet in thickness as the pit has

Figure 7. Shale pit of the United Brick and Tile Company. Adel, Dallas County, showing characteristic bedding of the Des Moines series.

been extended north into the valley side. The section is believed to be at the approximate horizon of members 5 to 12 of the pit of the Goodwin Brick and Tile Company. A uniform mix is also at present obtained here through the use of a planer.

[15]Correspondence with H. R. Straight.

Material used by the United Brick and Tile Company at its plant in the western limits of Adel is similar to the above. The pit (fig. 7) is approximately one-half mile north of the plant on a small tributary of the North Raccoon River in the SW¼ NE¼ sec. 30, Colfax Township (T. 79 N., R. 27 W.).

Section: United Brick and Tile Company,
Adel, Dallas County.

Member	Description	Thickness Feet	Thickness Inches
8	Glacial drift, including 10 feet of rusty sand and gravel, underlain and overlain by till	15-20	
7	Shale, red, with gray in middle, argillaceous and only slightly silty, fissile when dry	10-12	
6	Siltstone, gray, indurated, slightly calcareous		3
5	Shale, finely laminated light and dark gray, silty		5
4	Shale, carbonaceous, sandy		1
3	Clay, gray at top, purplish toward bottom, has appearance of underclay	4	6
2	Shale, red, argillaceous, contains irregularly shaped red-brown calcareous concretions which are dug out and rejected, slightly silty	4	
1	Shale, gray and red, in thick zones near bottom, splotched with red toward top, slightly silty	12	

This section is also believed to be at the approximate horizon of members 5 to 11 of the pit of the Goodwin Brick and Tile Company at Redfield, and a uniform mix is also at present obtained with the use of a planer.

The three sections give a picture of an abundance of shale and clay in this part of the county. The beds furthermore range in character, and constitute a satisfactory raw material when used together. The section in each case is essentially one of shale with a lesser amount of underclay. The shale beds range in the amount of silt and some of them are high enough in silt to be called siltstones. The color varies depending on whether iron compounds have been oxidized, but is of little or no importance from the ceramic standpoint. The total amount of silt and fine sand in the sections varies from one point to another, but with the use of the planer the mix is uniform from day to day, and changes so slowly that there is no difficulty in the operation of the presses and kilns.

Des Moines. The few small outliers of the Des Moines series in northwestern and eastern Augusta, southwestern Danville and western Union Townships total no more than 7 square miles in area. They consist of sandstone, coal, clay and shale known from several outcrops. These outliers contain beds of the more common and less refractory shale in some quantity,[16] but they offer no particular advantage with respect to quantity, location or amount of overburden. Buff-burning semi-refractory clays from the area in Danville Township were at one time used in the manufacture of pottery at Burlington.[17]

Franklin. The beds of the Des Moines series form the surface bedrock of most of Oakland and of the southwestern third of Morgan Townships. They are probably much like those of the series in Webster County to the west but lie beneath such thick mantle that the use of shale and clay from them is in any case not likely.

Greene. All except the western townships are believed directly underlain, beneath the mantle, by beds of the Des Moines series. Presumably quite like those of Boone County to the east. Cretaceous rocks overlie the Des Moines series in the following western townships:

All of Kendrick, Scranton and Willow.
A strip up to 3 miles wide in western Bristol, Jackson and Green Brier.
All except the northeastern quarter of Cedar.

Here also drift overburden is thick and there is an absence of deep valleys in which the beds might be exposed or close to the surface. For this reason alone any shales or clays of the series in the county have little or no potential value.

Grundy. Beds of the Des Moines series are believed to form the top of the bedrock of western Shiloh and northwestern Melrose Townships. They are not exposed but presumably resemble those along the Iowa River near Eldora to the west. They are beneath such thick overburden and the area is so lacking in deep valleys in which they might be exposed or near the surface that any shales and clays which might be present are considered to have little or no potential value.

Guthrie.[18] Beds of the Des Moines series directly underlie the mantle of drift and alluvium in most of the eastern townships and in narrow areas along the valleys of the larger streams in the western part, such as the Raccoon and Middle Raccoon Rivers, including townships as follows:

Richland with the exception of approximately a square mile in the southwest corner.
Cass with the exception of an irregularly shaped strip not more than a mile wide along the west side.
Jackson with the exception of a belt a few miles wide on the divide between the Middle and South Raccoon Rivers.
Penn with the exception of an irregularly shaped area of a few

[16]Op. cit. (Beyer and Williams), p. 430.
[17]Op. cit. (Galpin), p. 67-68.
[18]Bain, H. F., Geology of Guthrie County: Iowa Geol. Survey, vol. 7, pp. 428-446, 1897.

square miles beneath the divides of the western half.
An area of a few square miles in eastern Stuart. Approximately the northeastern quarter of Dodge.
A belt up to approximately a mile in width along the course of the Middle Racoon River in Victory.
A belt up to approximately a mile in width along the course of the South Raccoon River in eastern Valley.
A belt up to approximately 2 miles in width along the course of Beaver Creek in Beaver.
A belt up to approximately a mile or more in width along the course of the valley of the Middle Raccoon River in eastern Orange and the western half of Highland.
A belt up to a mile in width along the course of the valley of Brushy Fork in northern Seeley.

Elsewhere they are covered by the Cretaceous beds. They outcrop or are overlain by only thin mantle in many places along the deeper valleys and their shorter and deeper tributaries, including those of the Raccoon, Middle Raccoon, Wichita, Beaver and Brushy Fork. In these outcrops and in the coal mining operations the series has been found to contain much shale and sandstone. Much of the shale presumably is suitable for the manufacture of heavy clay products but offers no particular advantage as to quality, location or ease of extraction. It was at one time used in a plant at Panora.

Hardin.[19] Beds of the Des Moines series are believed to lie directly beneath the drift in all of Hardin County with the exception of the following township areas:

Etna.
All but southwestern Hardin.
Northeastern Ellis.
Northern Jackson.
Northwestern Clay.
Southern Eldora.
Eastern Union.
A small area along the South Fork of the Iowa River in southern Ellis and northern Tipton.

The drift cover is so thick over most of the area that the series is not exposed except along the Iowa River south of Steamboat Rock, along the lower part of some of the larger tributaries to the river in this part of its course, and along the South Fork in Ellis and Tipton Townships.

The series is known to consist of sandstone, up to 80 feet thick, and lesser amounts of shale, underclay and coal. The shale and underclay are generally beneath a considerable thickness of sandstone, thus making the shale and clay difficult to exploit.

The shale and clay have been used in the manufacture of heavy clay products at Eldora and other localities, and they have also been

[19]Beyer, S. W., Geology of Hardin County: Iowa Geol. Survey, vol. 10, pp. 271-278, 1900.

used in the manufacture of pottery. There is no doubt of their suitability for these products but they are handicapped by their great depth beneath drift and sandstone, and possibly by unfavorable geographic location. From the fact that pottery was at one time successfully manufactured at Eldora the conclusion is drawn that some of the underclay is buff-burning and might be classed as a No. 2 or medium quality fire clay. Areas most likely to have least drift overburden are outside of the Wisconsin moraine, in Eldora, Pleasant, Providence and Union Townships. The shales and clays should be nearest the surface along the sides of the deeper valleys in this area.

Harrison. The extent of the Des Moines series in Harrison County is not accurately known because of the thick mantle and absence of well records. It is believed to underlie all of the county except the southeastern townships, but to be overlain in the north-central townships by Cretaceous formations in addition to a thick layer of drift and loess. Presumably it contains abundant shales, similar to those of counties east of Harrison. The thickness of overlying materials everywhere in the county makes them of little or no potential value.

Henry.[20] Small scattered areas of the Des Moines series are present in the following township areas of southern Henry County:

Southern, western and northern Salem.
Southern and western Tippecanoe.
Southern Jackson.
Eastern Baltimore.

Much of the material is sandstone, although coal, shale and clay are present. The surface of the Mississippian limestone upon which the series lies is very uneven and the greater thickness of the sandstone, where it amounts to some tens of feet, is evidently due to the disposition in channels in the limestone. The areas underlain by the series are so small and the beds so thin that any shales or clays present hardly seem a likely source of raw material for a ceramic industry.

Humboldt. The lower part of the Des Moines series extends as a narrow strip through southern Humboldt County and forms the top of the bedrock beneath the drift of the following townships:

The southern sections of Weaver and Corinth.
Most of Beaver exclusive of the northwestern sections.
The greater part of Norway.

[20]Savage, T. E., Geology of Henry County: Iowa Geol. Survey, vol. 12, pp. 284-288, 1902.

Presumably the series here resembles that in Webster County to the south. It may also, if the same in character as the lower part of the series in Hardin County, be comprised more largely of sandstone. In any case it lies beneath such thick drift that any shales or clays present would appear to have but little potential value.

Jackson.[21] This county lies east of the main area of the Des Moines series and only small outliers, none more than a few square miles in extent are present, in southern Monmouth, southern and eastern Maquoketa, and southwestern Fairfield Townships. They do not exceed 60 feet in thickness, are of the lower part of the series, and consist principally of sandstone. Small thicknesses of shale and clay are present. These are presumably suitable for the manufacture of a range of clay products, but there is nothing in their quantity, quality or location that would make their use likely.

Jasper.[22] With the exception of the eastern part of Hickory Grove Township in the northeastern corner of Jasper County, the surface of the bedrock throughout is of the Des Moines series. The places where it is at the surface or close to it are, as Williams has described it, "not numerous but fairly well distributed over the southern half of the county." The best sections are along the valleys, but outcrops occur well up toward the upland also. In the following localities it is rather well exposed:

Elk Creek Township, sec. 32.
Lynn Grove Township, sec. 31.
Southern Richland and northern Lynn Grove Townships, along the North Skunk River and tributaries.
Mound Prairie Township, along the Skunk River in the NW¼ sec. 4.

There is an abundance of shales and clays in the series in these and other places in the county, of properties similar to those of Story County to the northwest, Polk County to the west, Warren County to the southwest, and Marion County to the south, in all of which they are at present being used. They were also formerly utilized in the manufacture of heavy clay products at Monroe.

Jefferson.[23] Beds of the Des Moines series form the surface bedrock beneath mantle of varying thickness throughout most of Jefferson County. The largest areas from which it is absent include parts of several townships:

Several square miles in northwestern Polk.
Approximately the northeastern quarter of Penn.
Walnut with the exception of areas of a few square miles each in northeastern, northwestern and central parts.

[21]Savage, T. E., Geology of Jackson County: Iowa Geol. Survey, vol. 16, pp. 625-630, 1906.
[22]Williams, I. A., Geology of Jasper County: Iowa Geol. Survey, vol. 15, pp. 310-316, 1905.
[23]Udden, J. A., Geology of Jefferson County: Iowa Geol. Survey, vol. 12, pp. 392-416, 1902.

A belt up to several miles in width in northern and eastern Lockridge.
A belt up to a few miles in width along Cedar Creek in Cedar.
A belt up to a few miles in width along Cedar Creek and tributaries in southern Round Prairie.

The area lies along the eastern boundary of the main deposit of Des Moines rocks and only the lower part of the series totalling approximately 150 feet at the most is thus represented. Outcrops, many of them meager, are present in numerous places along the larger valleys, and the rocks of the series are mostly covered with only thin mantle along these deeper valleys. Shale and clay are present in abundance in the series in Jefferson County but there are also, in common with the lower part of the series elsewhere, comparatively large thicknesses of sandstone, with lesser amounts of limestone and coal. Several coal beds and underclays up to a few feet are known.

The brick and tile plant which formerly operated at Fairfield secured some of its clay from a pit 2½ miles west of Fairfield in the NE¼ sec. 28, Center Township (T. 72 N., R. 10 W.). From the limited exposures recently available at this location it is apparent that there is present at least 5 feet of light gray to yellow shale, with a black coaly layer intercalated about 3 feet from the bottom. There may also be a thin coal on top of this shale. The material is in part an underclay and undoubtedly has the properties of a low grade fire clay. It is said to have been tried and found suitable for pottery by the plant at Fairfield.

Johnson.[24] Small outliers of the Des Moines series, none of them more than a few square miles in extent, are present in Monroe, Graham, Newport and East Lucas Townships. In these areas the series is thin and there is much sandstone. Shale and clay may be present but presumably not in great thickness or of unusual quality, and the series is not considered to have potential value as a source of raw material for a ceramic industry.

Keokuk.[25] This county lies along the eastern border of the main area of the Des Moines series, which directly underlies the mantle of the following township areas:

The western two-thirds of Prairie and Washington.
A belt a few miles wide extending through central Warren into Sigourney.
Southern Richland.
Southeastern Jackson.
The southwestern third of Benton.

Outliers up to a few square miles in area are found in Washington,

[24]Calvin, Samuel, Geology of Johnson County: Iowa Geol. Survey, vol. 7, pp. 79-83, 1897.
[25]Bain, H. F., Geology of Keokuk County: Iowa Geol. Survey, vol. 4, pp. 283-287, 1895.

Van Buren, Plank, East Lancaster, Clear Creek and Steady Run Townships. Only the lower part of the series having a thickness no greater than a few score feet is present. The cover of drift and loess in the county is stated to be as much as 200 feet thick in places, and it probably averages approximately 100 feet. The beds of the series are only exposed or close to the surface along the deeper valleys, but are also known from coal mining operations and from their use in the ceramic industry at What Cheer.

They contain important thicknesses of shale and clay as well as coal, sandstone and limestone. The surface upon which they lie has a relief of approximately a few hundred feet, so that individual beds are not continuous at a given horizon.

The principal and almost only use of the shales and clays of the series has been by two plants at What Cheer. The What Cheer Clay Products Company is one-half mile south of What Cheer in the NE¼ sec. 15, Washington Township (T. 76 N., R. 13 W.). Raw material has been secured for many years from pits in the valley of Coal Creek, the present workings lying north of the plant on the east side of the valley.

Section: What Cheer Clay Products Co.,
What Cheer, Keokuk County.

Member	Description	Thickness Feet	Inches
4	Alluvium and till	5-10	
3	Coal, weathered	2-4	
2	Clay, has fracture and appearance of underclay, vague stratification, somewhat silty, very tough when wet, contains a few large limestone concretions up to 4 feet across	10-12	
1	Shale, dark blue gray, silty, sharp contact on top with 2.	8	

These materials (members 1 and 2) are at present (1942) being removed with a dragline shovel and mixed in accordance with results desired. Yellow surface clay, presumably loessal in origin, has at times been obtained from Eddyville and used in the mixture.

Higher strata are exposed in older workings, pit No. 1, in the SE¼ sec. 10.

Section: What Cheer Clay Products Co., Pit No. 1,
What Cheer, Keokuk County. (1933)

Member	Description	Thickness Feet	Inches
5	Till and alluvium; overburden	5-30	
4	Shale, black, carbonaceous. (T)	8-10	
3	Sandstone, well-cemented, calcareous, present only in north end of pit, absent above the coal	4	
2	Coal present in south end only, apparently was cut out by sandstone at the north, contains concretions up to 5 feet in diameter, this was mined by stripping.	5	6
1	Clay, underclay in character, light gray, silty. (T)	8	

Member 1 of this section is correlated with the upper part of member 2 of the section of the present pit. It was at one time the principal raw material; member 4 was used to some extent in admixture with it. A fault of not more than a few feet throw crosses this pit in an east-west direction.

The shale or clay mix from these pits burns buff and fires to a harder product at a higher temperature than much of the shale from the series. This is related to the underclay character of part of the material. It is believed not sufficiently free of small pyrite grains to find a satisfactory use in the manufacture of fire brick or buff face brick.

The plant of John Nelson on the west edge of What Cheer also uses a few feet of weathered shale from the Des Moines series, along with surface clay, in the manufacture of tile and art pottery.

Lee.[26] The Des Moines series forms the top of the bedrock beneath parts of several townships, as follows:

The western half of Cedar.
The western half of Harrison.
A belt extending northwest-southeast through Van Buren into southwestern Charleston and northwestern Des Moines.
An irregular area extending across northwestern Marion and through central Pleasant Ridge.
An irregular area which includes most of southern Marion and northwestern West Point.
A belt extending northwest-southeast through eastern Charleston.

The beds are of the lower part of the series, are believed to be not over a few score feet in thickness, and generally lie in depressions in the surface of the older rocks which has a relief of a few hundred feet. In common with the lower part of the series elsewhere there is much sandstone. Shale, coal and accompanying underclay are also present. So far as known the deposits of shale and clay are not thick or extensive and have no advantage as to quality, location or ease of exploitation.

Louisa.[27] This county has two small outliers of the series only a few square miles in extent in central Oakland and southern Elm Grove Townships. They do not exceed approximately 20 feet in thickness and contain some shale, clay and coal as well as abundant sandstone. The shales and clays have little or no potential value as ceramic materials because of their limited quantity, as well as their lack of favorable geographic location.

Lucas.[28] The Des Moines series forms the top of the bedrock of

[26]Keyes, C. R., Geology of Lee County: Iowa Geol. Survey, vol. 3, pp. 352-356, 1895.
[27]Udden, J. A., Geology of Louisa County: Iowa Geol. Survey, vol. 11, pp. 93-95, 1901.
[28]Lugn, A. L., Geology of Lucas County: Iowa Geol. Survey, vol. 32, pp. 143-169, 1927.

the entire county and is well known from surface exposures, drill records and coal mining operations. Good outcrops and places where the formation is covered by only thin mantle are numerous along deeper valleys in the northeastern six townships, and are also present, although to a lesser extent, in western and southern townships. The drift ranges up to 400 feet in thickness. There are no exposures of the series in Union Township and few in Otter Creek. The series increases in thickness from northeast to southwest and most of the entire thickness of approximately 750 feet is present in the southwestern part. The surface of the series and the underlying unconformity have considerable relief.

The series contains an abundance of shales and clays, as well as much sandstone and lesser amounts of coal and limestone. There are certainly shales and clays suitable for the manufacture of ceramic ware near the top of the series in the county. Whether any given locality possesses a sufficiently thick section of clay and shale, without undesirable interbedded sandstone, limestone, or coal, and lying beneath only thin waste overburden, can only be determined by prospecting the site. There is at present no ceramic industry within the county.

Madison.[29] The Des Moines series underlies all of Madison County but is overlain by beds of the Missouri series as well as by mantle over much of the area. The eastern boundary of the overlying Missouri series is very irregular. It extends east into the Des Moines area as tongues along major divides. Township areas where the Des Moines series is not covered by the Missouri series and where the Des Moines series is the top of the bedrock are as follows:

All of Lee and Crawford.
The eastern half of Jefferson and broad belts up to a few miles wide along the major stream valleys in the western half, extending into Madison, Union and Douglas.
The eastern third of Union and broad irregular belts up to a few miles wide in the western and southern parts along North River, Cedar Creek and Middle River.
An irregular belt up to a few miles wide along North River in the eastern half of Douglas.
A belt less than a mile wide along Middle River in Lincoln.
An irregular area up to a few miles wide in the northern part of Scott, principally along Middle River and small tributaries.
A belt up to approximately a mile wide along Jones Creek in the eastern half of Scott.
All of South except for tongues extending a few miles east from the western and southern boundaries between Middle River, Jones Creek and Clanton Creek.

[29]Tilton, J. L., and Bain, H. F., Geology of Madison County: Iowa Geol. Survey, vol. 7, pp. 504-508, 1897.

An irregular area along tributaries to Clanton Creek in northern Ohio, and an irregular belt along South River and tributaries in the southeastern part.

Rocks of the series outcrop in many places over the eastern half of the county, particularly along deeper valleys such as that of Clanton Creek, and must also lie close to the surface along the sides of many of the valleys. Sections described by Tilton and Bain predominate in shale and clay; there are small thicknesses of limestone and coal, and a negligible amount of sandstone.

The following section from a ravine south of Patterson in the NW¼SE¼ sec. 32, Crawford Township, (T. 76 N., R. 26 W.), is considered representative.

Member	Description	Thickness Feet	Inches
14	Shale, black	2	
13	Unexposed.	21	
12	Shale, blue, clayey above, gray, sandy below	16	
11	Limestone, dense, drab, fossiliferous	1	
10	Shale, blue, clayey	3	
9	Sandstone, gray		5
8	Shale, clayey, blue and gray	27	
7	Sandstone, gray, nodular	1	
6	Shale, sandy, drab	27	
5	Limestone, arenaceous, gray, fossiliferous		9
4	Shale, black	2	
3	Shale, gray, clayey (only partly exposed)	30	
2	Coal.		6
1	Shale, red (only partly exposed)	32	

Beyer and Williams[30] have described sections on a small branch of Chariton Creek in secs. 27, 34 and 35, and north of St. Charles in sec. 11 of South Township; 2 miles southwest of Bevington on the south bank of the Middle River and south of Patterson in the NW¼ SE¼ sec. 32, Crawford Township.

From these outcrops it is known that the series contains an abundance of shales and clays, but apparently none is of unusual quality. The shale and clay are reasonably certain of being as suitable for ceramic purposes as those of Dallas County to the north where they are used at Adel and Redfield. Their use involves particularly the securing of locations lacking excessive overburden or beds of useless material such as sandstone, limestone and coal. So far as known there has been no use of the Des Moines shales and clays within the county.

Mahaska.[31] The top of the bedrock of this county is formed of the Des Moines series with the exception of northwest-southeast

[30] Op. cit., (Geology of Clays), pp. 447-450.
[31] Bain, H. F., Geology of Mahaska County: Iowa Geol. Survey, vol. 4, pp. 336-342, 1895.

belts up to a few miles wide along the course of the North Skunk River Valley through Monroe, Pleasant Valley and Union Townships; along the course of South Skunk River Valley through White Oak, Spring Creek, Adams, Madison, Black Oak and Richland Townships; along the course of the Des Moines River through Des Moines, Jefferson and Scott Townships; and along the course of Cedar Creek in Cedar Township. The series is absent only from beneath the valley bottoms of these streams, and only the lower part, up to approximately 60 feet in thickness, is present. Outcrops and places where the shales are close to the surface are present only on the sides of the larger valleys above the beds of the Meramec series. Elsewhere the mantle of glacial drift and loess is generally thick. Coal mine workings, of which there have been many in the past, serve as an indication of the presence of these Des Moines shales below the surface. The series is known from numerous outcrops, particularly along Muchackinock Creek, and from mine shafts and records. It is known to contain argillaceous gray shale up to 30 feet thick and carbonaceous shale up to 50 feet thick, as well as considerable sandstone, coal and limestone.

The shale has been used in the manufacture of heavy clay products at Oskaloosa for many years. The plant of the Oskaloosa Clay Products Company is located immediately east of the city in the SW¼ sec. 17, Spring Creek Township (T. 75 N., R. 15 W.). The pit, located north of the plant on the east side of Spring Creek, exposes over 25 feet of the Des Moines series.

Section: Oskaloosa Clay Products Co., Oskaloosa, Mahaska County.

Member	Description	Thickness Feet	Inches
5	Till and loess	20	
4	Shale, blue gray, tough and plastic when wet, somewhat carbonaceous, but not as much as member 2, and less carbonaceous toward top, generally argillaceous but silty in some places; contains irregular clay ironstone concretions toward the top. (T)	6	
3	Limestone, blue, nodular	1	
2	Shale, argillaceous, sheeted, carbonaceous throughout, sharp contact with member 1 below, cuts member 1 at low angle. (T)	4	6
1	Shale, gray, finely laminated, partly silty and sandy, micaceous. (T)	15	6

Members are used in different proportions, dependent upon the results in pressing and firing. A few years ago the blend consisted of approximately 50 percent of member 1 of the above section, 25 percent of member 2, and 25 percent of member 3 and member 5 together.

Clay secured in the vicinity of Eddyville in this county was at one time used in the manufacture of pottery, and no doubt clay suitable for this purpose is present elsewhere in the county within the Des Moines series. There is certainly also an abundance of shale and clay suitable for the manufacture of heavy clay products. The sections at other places, even at the same horizon, may not be the same as that described above, but is likely to contain an equally large amount of shale or clay.

Marion.[32] The Des Moines series forms the top of the bedrock of Marion County except for belts up to a few miles wide along the Des Moines and Skunk Rivers and some of their larger tributaries in Lake, Clay, Prairie and Polk Townships. In the deeper parts of the valleys of these areas the Des Moines series has been removed by erosion, and the underlying beds of the Meramec series, chiefly limestone, form the top of the bedrock. Outcrops and places where rocks of the Des Moines series are close to the surface are found along sides of the deeper valleys.

The stratigraphy is known from outcrops, coal mining operations and well records. Sandstone is believed present in greater amount than in some of the surrounding counties but shales and clays of the usual range are present in abundance and have been used in the manufacture of heavy clay products at Harvey and Knoxville.

The plant of the Oskaloosa Clay Products Co., located north of Harvey on the north side of the valley of English Creek in the SW¼ sec. 3, Clay Township (T. 75 N., R. 18 W.), is the only plant at present operating in Marion County. The pit (fig. 8) is northwest of the plant and is being extended to the west.

Section: Oskaloosa Clay Products Co.,
Harvey, Marion County.

Member	Description	Thickness Feet	Thickness Inches
10	Loess and topsoil, possibly thin drift at base	10	
9	Sandstone, dark red brown, weathered and crumbly, contains plant impressions and carbonized fragments, and weathered red sandstone fragments	8	
8	Coal, weathered	1	3
7	Clay (underclay), silty, joint cracks near top, stained red and in lower part some are filled with ocherous powder, tendency toward stratification in lower part.	3	
6	Shale, dark blue gray; somewhat silty, finely laminated or straticulate toward bottom	4	
5	Sandstone, slabby, ferruginous, mottled, grades to member 4 below and member 6 above		4-6
4	Shale, gray brown, silty, laminated, grades to dark blue argillaceous zone at base	6	
3	Limestone, light reddish buff, deep red brown stain		

[32]Miller, B. L., Geology of Marion County: Iowa Geol. Survey, vol. 11, pp. 146-153, 1901.

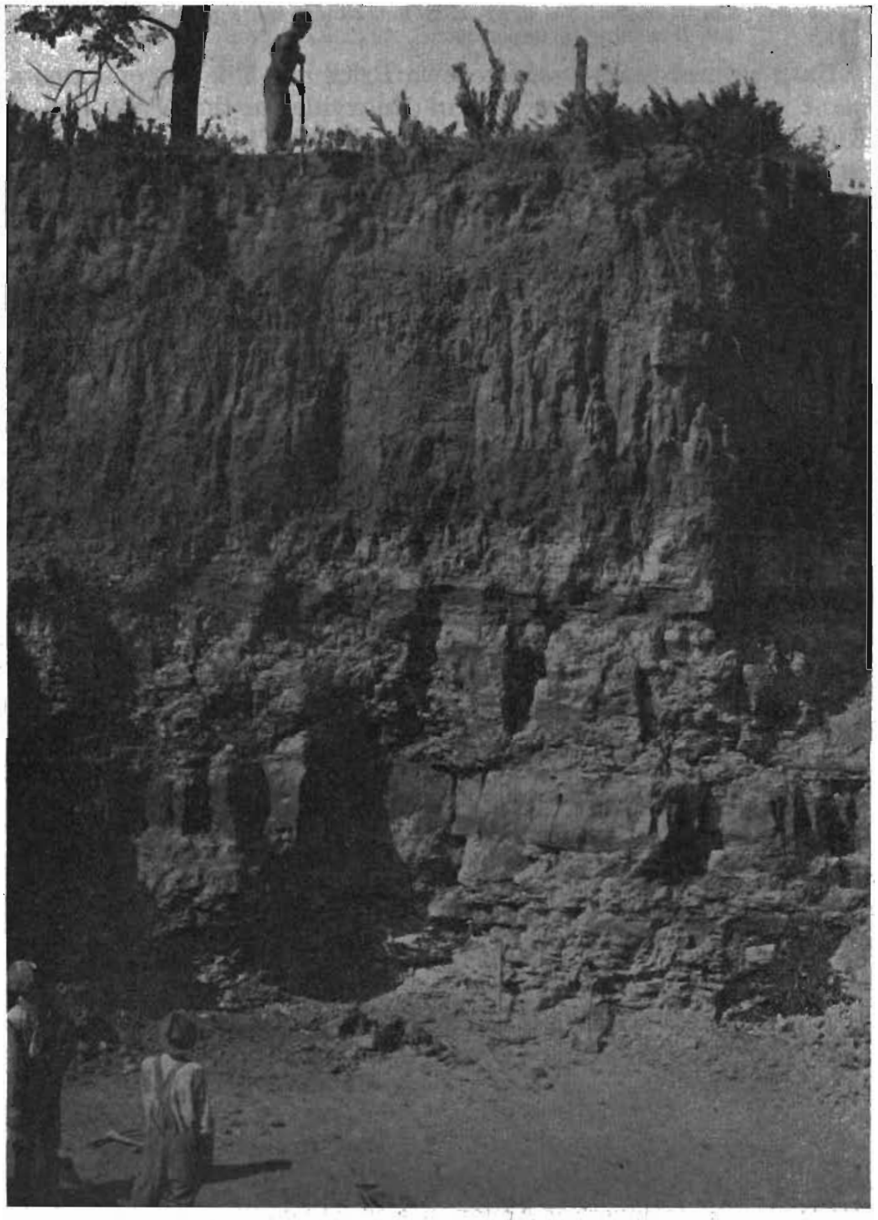


Figure 8. Shale pit of the Standard Clay Products Company, now the Oskaloosa Clay Products Company, Harvey, Marion County.

	characteristically on joints	1	
2	Siltstone.	1	
1	Clay (underclay), gray, silty and sandy, more plastic and less silty in upper part	5	

Until several years ago, the Iowa Brick and Tile Co. operated a plant in the northeastern part of Knoxville, in the NW¼ sec. 6, Knoxville Township, (T. 75 N., R. 19 W.). The section can only be approximately described, since because of disuse the pit face had slumped considerably and become covered with slope wash.

Section: Iowa Brick and Tile Company, Knoxville, Marion County.

Member	Description	Thickness Feet	Inches
4	Till.	2	
3	Shale, gray, weathered, contains limestone concretions and contains thin coal beds	10	
2	Covered.	25	
1	Shale, light gray on weathered face, fresh material in part a brownish gray, some streaks of carbonaceous shale	8	

Fire clay, according to former workmen at the plant, lies below the section given above and the buff color of ware which had been produced confirmed this. Some of the covered upper part of the section is also an underclay with fire clay characteristics.

Marshall.[33] The Des Moines series forms the top of the bedrock beneath the surface materials of the following township areas:

All of Liberty, Minerva, State Center, Eden and Logan.
All of the upland area away from the valleys of the Iowa River and Honey Creek in Bangor.
An area several square miles in the southwestern corner of Liscomb.
Practically all of Iowa.
A strip approximately a mile wide in the northwestern part of Taylor.
All except a belt up to a few miles wide along the valley of the Iowa River in Nianetta.
A strip less than a mile wide along the western boundary of Linn.
The upland in the western part of Timber Creek between Linn and North Timber Creeks and between North Timber and South Timber Creeks.
All except a few square miles in the northeastern corner of Jefferson.
A few square miles in the southwestern corner of Green Castle.

There is also an isolated outlier in the southwestern corner of Vienna Township, and there may be other small patches beneath the drift.

The surface materials form such a thick cover that the rocks are exposed only in a few places along some of the valleys, as along Honey Creek northwest of Albion in secs. 34 and 36, Iowa Township, (T. 85 N., R. 19 W.). According to Beyer, shales and clays are

[33]Beyer, S. W., Geology of Marshall County: Iowa Geol. Survey, vol. 7, pp. 227-229, 1897.

numerous, but so far as known they are like those elsewhere in the series. They have not been used in the ceramic industry, and lie beneath such thick cover of drift and possibly also of sandstone that there is no incentive for using them.

Monroe.[34] The Des Moines series forms the top of the bedrock beneath most of Monroe County, being absent only from an area of a few square miles in the northeastern corner of Pleasant Township. Although generally concealed beneath the mantle of drift, alluvium and loess, there are many outcrops and many places along valley sides where it is close to the surface, particularly in the northeastern townships. Definite outcrops are in part sandstone or limestone as only beds resistant to weathering are likely to appear in outcrops, and the presence of these may, as elsewhere, be taken as an indication of the possible presence near the surface of associated shale or clay. It is quite apparent, from the outcrops and coal mining records, that the Des Moines series in Monroe County contains an abundance of shale and clay suitable for the manufacture of heavy clay products. Fire clay is included in the section described by Beyer and Young[35] from the vicinity of Foster. These are believed to be underclays typical of the Des Moines series, and so far as known, of the same general quality as elsewhere.

Section beneath upland near Foster, Monroe County.

Member	Description	Thickness Feet	Inches
22	Drift.	90	
21	Sand and gravel.	2	
20	Fire clay.	6	
19	Shale, gray.	8	
18	Clay shale, light colored	14	
17	Shale, black.	11	
16	Coal.	1	
15	Fire clay.	2	
14	Shale, gray and arenaceous.	22	
13	Shale, dark.	6	
12	Coal.	1	6
11	Shale, dark.	2	
10	Sandstone, shaly.	4	
9	Fire clay.	3	
8	Shale, clayey.	15	
7	Sandstone, shaly.	19	
6	Hard ledge.	1	6
5	Sandstone.	10	
4	Shale, black.	5	
3	Sandstone, shaly.	31	
2	Hard ledge.	2	
1	Sandstone.	14	

[34]Beyer, S. W. and Young, L. E.; Geology of Monroe County: Iowa Geol. Survey, vol. 13, pp. 365-377, 1903.
[35]Op. cit., p. 373.

The county has at present no clay products industry and evidently has never had one which made use of the Des Moines shales and clays to any extent. Shale and clay suitable for ceramic purposes are accessible along many valleys, particularly in northeastern townships.

Muscatine.[36] The rocks of the Des Moines series form the top of the bedrock over an area which includes parts of several townships:

A strip approximately a mile in width across northern Fruitland.
The southeastern half of Bloomington.
Sweetland with the exception of a narrow strip along the Mississippi River.
Montpelier with the exception of a narrow strip along the river and small areas up to approximately a square mile in extent in the northwestern part.
The southern sixth of Wilton.
The southern sixth of Fulton.

The series ranges up to approximately 100 feet in thickness and decreases rapidly in thickness toward the north. Outcrops are numerous along the deep valleys tributary to the Mississippi and are present in the bluffs, as at Wyoming Hill east of Davenport. Sandstone is prominent in many of these, attaining a thickness of as much as 100 feet. This is in keeping with the character of the lower part of the Des Moines series, of which beds in this county are a part. Shale and clay are also present and that utilized in potteries which formerly operated at Fairport was presumably underclay from the series. The thick sandstone and the lack of reasonable thickness of shale and clay in the series weighs against the possibility of extensive use of any of the materials in a ceramic industry. There is at present no clay products industry in the county.

Pocahontas. Beds of the Des Moines series are believed to underlie directly surface materials of the southeastern townships. The series boundary is not definitely known but is thought to pass northeast through Colfax and Lincoln Townships, and east through central Garfield Township. The beds do not outcrop and little is known regarding them from drilling records, but they are believed to contain shales and clays similar to those elsewhere in the northern part of the Des Moines area, as at Fort Dodge, Webster County.

Polk.[37] Beds of the Des Moines series underlie the entire county. North of Des Moines the mantle is 100 feet or more in thickness and the beds outcrop only in places along the Des Moines River. In

[36]Udden, J. A. Geology of Muscatine County: Iowa Geol. Survey, vol. 9, pp. 303-316, 1899.
[37]Bain, H. F., Geology of Polk County: Iowa Geol. Survey, vol. 7, pp. 292-302, 1897.

the southern part of the county outside of the area of Mankato glaciation, they are exposed or are close to the surface in many places along the deeper valleys, such as those of the Raccoon and Des Moines Rivers and their deeper tributaries. Their character is known from these exposures and from many coal mining records and operations. Shales and clays are abundant close to the top of the section underlying most of the county. Thick beds of sandstone, coal in commercial thickness, and thin limestones make up the remainder.

The shales and clays have been extensively used in the clay products industry at Des Moines, and to some extent elsewhere in the county, for many years. They are at present (1942) used in the manufacture of structural clay products by the Des Moines Clay Co. and the Goodwin Tile and Brick Co., and in the manufacture of sewer pipe and tile by the Iowa Pipe and Tile Co.

The sections exposed in the shale pits of the three companies give a clear picture of the materials available in the upper part of the series in Polk County, except for places where they are cut out by channel sandstone. Two of the pits are in the northern part of Des Moines, that of the Des Moines Clay Co. on the west side of the Des Moines River Valley in the NW¼ sec. 21, Saylor Township (T. 79 N., R. 24 W.) and that of the Iowa Pipe and Tile Co. on the east side of the valley in the W½ sec. 22, Saylor Township. The plant of the Des Moines Clay Co. is immediately south of its pit, while that of the Iowa Pipe and Tile Co. is a mile south of the pit and on the east side of the Des Moines River Valley at East Fourth and Hayes Streets, Des Moines.

Section: Des Moines Clay Co.,
Des Moines, Polk County, (1933).

Member	Description	Thickness Feet	Thickness Inches
28	Drift.	12-15	
27	Shale, notably plastic, buff, weathered	3-4	
26	Shale, notably plastic, red, weathered	1-2	
25	Shale, notably plastic, buff, weathered	1	
24	Shale, notably plastic, dull purple, weathered	1	
23	Shale, notably plastic, light gray, mottled with buff, weathered.	1-2	
22	Shale, banded light gray and red, weathered	3-5	
21	Shale, dark gray, weathered		6
20	Shale, dull purple mottled with buff, weathered	3	
19	Shale, buff, dense, weathered	2	
18	Shale, somewhat fissile, 1 foot of blue limestone near bottom; weathers buff. (T)	8	6
17	Sandstone, calcareous.	1	2
16	Shale, carbonaceous, with sandstone laminae		4

		Feet	Inches
15	Clay (underclay), lower 6 inches dark blue and brown, gray above, top 1½ feet dark gray, angular fracture, generally plastic and argillaceous but silty toward top. (T)	6	4
14	Shale, dull red with irregularly gray streaks, partly silty.	3	
13	Shale, gray, silty	8	
12	Shale, generally gray but banded red and gray toward top, fissile, weathers to flakes.	1	6
11	Covered, believed to be red and gray shale	10	
10	Shale, light gray, silty, with flattened ferruginous concretions.	2	9
9	Shale, red.	3	
8	Covered, believed to be gray silty shale	5	9
7	Shale, dark gray, carbonaceous, sheeted	1	2
6	Coal, carbonaceous shale and sandstone irregularly interbedded.	1	
5	Coal.	1	8
4	Clay (underclay), dark gray, weathering light gray, lighter toward bottom, starchy fracture, silty, particularly in upper part. (T)	4	9
3	Shale, carbonaceous, silty.		2
2	Shale, gray, silty, angular fracture, hard. (T)	2	
1	Sandstone, noncalcareous.	2	

The sandstone member 17 formed the floor of the pit as it was being operated in 1933, and members 18 to 27 exclusive of the limestone of 18 were being used as raw material. There were at that time two lower benches in the pit, one on top of member 7 and the other on top of member 10. The upper members lying close to the surface are believed to have been rendered more plastic through leaching incident to weathering. Beds of this part of the section are notably different in color but believed rather alike as regards plasticity, silt content, and similar features. The various shale members of the section differ more in color than they do in properties important to the manufacturer such as plasticity and silt content. The properties of the raw material used at the plant are controlled through proper admixture of shale from different parts of the section.

The pit of the Iowa Pipe and Tile Co. had the best exposed section in 1942, standing in a vertical wall from the floor of the pit to the base of the drift. The section is much like that at the pit of the Des Moines Clay Co. and the sandstone (member 17) and the limestone of member 18 serve as horizon markers.

The third plant is that of Goodwin Tile and Brick Co. at Southeast Eighteenth Street and Hartford Avenue in southeastern Des Moines. This is on the south side of the Des Moines River Valley in the S½ sec. 11, Lee Township, (T. 78 N., R. 24 W.). A plant has operated at this locality for many years and workings from which shale was secured have extended along the valley side for a few hundred yards. The present opening is immediately south of the plant.

Section: Goodwin Tile and Brick Co.,
Des Moines, Polk County.

Member	Description	Thickness Feet	Inches
10	Loess.	0-15	
9	Shale, argillaceous, softened by weathering, wide range in color, developed through weathering, upper few feet dull purple, red and gray below.	10	
8	Limestone, dense, fine-grained, weathers brown, "cap-rock."		8
7	Shale, roughly laminated with some laminae dark gray argillaceous, others light gray silty, in part a uniform gray color and silty, grades to:	6	
6	Shale, carbonaceous, argillaceous, thin laminae of coal.	1	6
5	Clay (underclay), slightly silty, gray brown to yellow where near surface and weathered, starch-like fracture.	4-6	
4	Shale, silty, light gray, finely straticulate, light and dark, slight tendency toward shaly parting, contains small sandy calcareous concretions.	12	
3	Shale, argillaceous, dark gray brown, shaly parting.	1	2
2	Sandstone, or siltstone, light gray, jointing prominent, resembles member 4 in general appearance but firmly indurated.	3	
1	Shale, light gray, silty or sandy, much of it in thin bands, light and dark gray, without shaly parting, resembles member 4, but is possibly more indurated.	10	

The limestone member 8 is the limestone of member 18 of the section at the pit of the Des Moines Clay Co. The three pits are thus working at approximately the same horizon in the Des Moines series. The beds above and below the limestone are, as one would expect, much alike at the three pits but vary somewhat with the character of the original deposition and the degree of weathering. The unweathered materials of the three pits, taken as a whole in each case, differ in the percentage of silt or fine sand in the composite, and in the amount of carbonaceous shale, thin coal laminae and underclay.

At the plant of the Goodwin Co. as at others, shale and clay from different horizons are mixed in proportions such as secure the most desirable results in pressing and burning. In making face tile, for example, a mixture of 30 percent of member 9 and 70 percent from below member 9 is used. Member 9 helps to produce a red color. The ware is burned at 1900° to 2000° F.

By way of summary, shale and clay suitable for heavy clay products purposes are abundant in Polk County. They are particularly accessible in the vicinity of Des Moines, and their suitability there is shown by the extent to which they have been used by the industry.

Poweshiek. The Des Moines series forms the top of the bedrock beneath a considerable part of the southwestern townships, including:

The southwestern third of Grant.
All except a strip up to a mile or more in width in the northeastern corner and along the east side of Washington.
An area of less than a square mile in southwestern Pleasant.
All of Sugar Creek except a strip a mile or more in width adjacent to the course of the Skunk River Valley.
All of Union with the exception of a few square miles in the northeastern corner.
Approximately two-thirds of southern and western Jackson.
Approximately the southwestern fifth of Deep River.

The series[38] is covered with thick drift beneath most of the area, but is exposed in many places along North Skunk River and Buck Creek, and it is also known from well records. The thickness of the series decreases toward the east and lies upon a surface having a relief up to as much as approximately 200 feet.

The section described by Stookey from the south bank of the Skunk River in the NW¼SW¼ sec. 36, Sugar Creek Township, (T. 78 N., R. 16 W.) shows much shale and some clay, along with lesser amounts of sandstone, coal and limestone:

Member	Description	Thickness Feet	Thickness Inches
9	Drift.	8	
8	Shale.		6
7	Coal.		10
6	Limestone.	1	
5	Shale, bituminous.	18	
4	Coal.	1	
3	Fire clay.	2	
2	Shale, variegated.	7	
1	Sandstone, brown.	2	

So far as known shale and clay from the Des Moines series have not been used in the manufacture of clay products in Poweshiek County. There is nothing in the quality of the shale and clay in the series, or in its location with respect to markets to make its use particularly attractive.

Sac. The boundaries of the area underlain by the Des Moines series in Sac County are not very definitely known because of the thick drift cover and absence of outcrops, but the series is known to underlie much of the southern part. There are also large areas where it is overlain by Cretaceous beds in addition to the mantle.

[38]Stookey, S. W., Geology of Poweshiek County: Iowa Geol. Survey, vol. 20, pp. 258-260, 1910.

It is thought to lie directly beneath the mantle of the following Township areas:

A strip less than a mile wide along the southern boundary of Boyer Valley.
A third of Jackson, in the southern and southeastern parts.
All except the northwestern approximate fifth of Cedar.
Clinton with the exception of a strip approximately one-half mile wide along the western border.
All of Wall Lake.
The northwestern two-thirds of Coon Valley.
The southeastern quarter of Wheeler.
All of Levey.
All of Viola with the exception of the southeastern quarter.
A small area not more than a square mile in extent in northwestern Sac.

The series does not outcrop in the county and but little is known of it from well records. It seems reasonable to believe, however, that it has much the character of the lower part of the series elsewhere. Shale and clay probably constitute much of the upper part of the series as it is represented in the county. The material lies beneath such heavy overburden, that if for no other reason there seems little possibility of its economic use.

Scott. Only outliers or parts of outliers of the Des Moines series are present in Scott County. The largest area is part of the large outlier which extends from Muscatine County to the west; this forms the top of the bedrock beneath all of Buffalo Township except for a narrow strip a mile or two in width along the Mississippi River, with minor extensions eastward into northwestern Rockingham and southwestern Davenport Townships, and northward into southwestern Blue Grass Township. Other small outliers, none of them more than a mile or two in extent, are present in the northern and eastern parts of Sheridan and in central Lincoln, southern Le Claire and eastern Pleasant Valley Townships.

The series [39] known from natural outcrops, shale pits, coal mining records and well records, totals as much as 200 feet in some places, lies upon a surface having relief of a few hundred feet, and contains, much shale and clay with lesser amounts of sandstone, limestone and coal. Until a few decades ago shale and clay secured from a pit immediately northeast of the village of Buffalo in the NE¼ sec. 22, Buffalo Township (T. 77 N., R. 1 E.) were used by the Davenport Brick and Tile Co. at its nearby plant east of Buffalo. The section as described by Norton is as follows:

[39] Norton, W. H., Geology of Scott County: Iowa Geol. Survey, vol. 9, pp. 463-469, 1899.

Member	Description	Thickness Feet
7	Loess, middle and upper phases	7
6	Till, red, brownish yellow.	5
5	Shale, weathered, gray and ocherous yellow, readily disintegrating, joints and seams and spaces between laminae filled with ocherous accumulations.	5
4	Shale, black, finely laminated	12
3	Shale, gray.	3
2	Shale, dark drab and black, brittle, fine-grained, containing ferruginous nodules and nodular layers.	42
1	Shale, gray, disclosed in shaft below bottom of pit	26

This section is believed typical of the series in the county.

Shale from this series has recently been used, along with some overlying drift, as the argillaceous constituent in the manufacture of Portland cement by the Dewey Portland Cement Co. at its plant 1½ miles east of Buffalo. In the clay pit, about one-half mile north of the plant, there is exposed only approximately 6 feet of a blue-gray plastic clay, (T), formed by the weathering of shale, and overlying drift of varying thickness.

These Des Moines shales were also used for many years in the manufacture of clay products at Island City, 3 miles southwest of Le Claire.

Shelby. Boundaries of the Des Moines series in Shelby County are not certainly known because of the thick drift and absence of outcrops. They have been located largely on the basis of well records and the southern boundary is believed to run approximately from the southwestern corner of Washington Township on the west to below the middle of the eastern boundary of Jefferson Township on the east. The series would thus form the bedrock beneath all of Grove, Union and Greeley Townships; and the northern parts of Washington, Westphalia, Douglas and Jefferson Townships. Nothing definite is known regarding the stratigraphy, but the series presumably contains shales and clays similar to those elsewhere. The beds lie, however, beneath such heavy overburden that they have little potential value.

Story.[40] The county is underlain with the Des Moines series except for an area adjacent to the confluence of Squaw Creek and Skunk River valleys in the western part. While the boundaries are none too certainly known, the series is believed absent from the following township areas:

[40]Beyer, S. W., Geology of Story County: Iowa Geol. Survey, vol. 9, pp. 190-195, 1899.

All of Franklin with the exception of the southwestern corner and an area of several square miles in the north.
Several square miles in the northeastern corner of Washington.
Several square miles in the northwestern corner of Grant.
A strip up to a few miles wide along the western side of Milford.
Several square miles in southwestern Howard.
Approximately a square mile of southeastern Lafayette.

Beds of the series are exposed to some extent along the Skunk River and the lower parts of some of its tributaries in the vicinity of Story City and Roland, and along West Indian Creek in the vicinity of Nevada and Maxwell. Sandstone, shale and clay make up the material of these exposures, and the shale and clay have been used in the manufacture of ceramic products at Nevada, Roland and Maxwell. The most definite information regarding the character of the shale and clay of the series has been obtained from the shale pit of F. C. McHose and Son on the west side of West Indian Creek west of Nevada in sec. 1, Nevada Township (T. 83 N., R. 23 W.), where the shales and clays have been used in the manufacture of heavy clay products for many years.

Section: F. C. McHose and Son
Nevada, Story County

Member	Description	Thickness Feet	Thickness Inches
6	Drift.	0-15	
5	Shale, gray and red, banded, mostly low in silt, contains calcareous ferruginous concretions, stratified, weathered.	12	
4	Shale, carbonaceous, slickensided, plastic, with thin coal laminae and siltstone seams.		8-12
3	Shale in lower half, silty, variegated and mottled, generally dark gray buff, lacks visible stratification, irregular joints. Grades in upper part to clay (underclay) 3 feet thick, gray buff, lacks silt, starchy fracture.	20	
2	Sandstone, calcareous.		2
1	Shale, maroon, argillaceous.	4	

The shale and clay are undoubtedly abundant in the Des Moines series in Story County, but are almost everywhere beneath thick overburden.

Van Buren. The main area of the Des Moines series extends into Van Buren County and underlies all of the county with the exception chiefly of the country adjacent to the courses of the larger valleys. It forms the top of the bedrock of the following township areas:

Village except for a northwest-southeast strip a few miles wide adjacent to the course of Des Moines River Valley.
All of Lick Creek except a strip up to a mile or two wide along the course of Des Moines River Valley.
All of Chequest except an area of several square miles along Chequest Creek in the eastern part.

Areas up to several square miles each in northwestern, northeastern, southwestern and extreme southern Van Buren.
The northern half of Washington.
All of Des Moines with the exception of an area of approximately a square mile in the northeastern corner.
Areas of a few square miles each in the southwestern and southeastern corners of Henry.
Several square miles in the southwestern part of Bonaparte and a few square miles along the eastern border.
All of Union except an area of less than a square mile in the southwestern quarter.
Cedar with the exception of several square miles along the valley of Cedar Creek in the northeastern corner and an area of a few square miles in the southeastern corner.
The western third of Harrisburg except for the southwestern corner, and a strip less than a mile wide along the eastern side.
The western half of Farmington.
All of Vernon and Jackson.

Shales or clays of this series[41] outcrop or are close to the surface along many of the valleys underlain by the formation. Shale similar to that in the series elsewhere is present in appreciable thickness. The thickness ranges to approximately 75 feet but is much less beneath much of the area.

Of the numerous sections described by Gordon, the following from a mine in eastern Village Township, is rather typical.

Member	Description	Thickness Feet	Thickness Inches
12	Concealed.	20	
11	Shale, blue, argillaceous.	10	
10	Coal.		6
9	Shale, arenaceous, filled with plant remains		10
8	Coal.		6
7	Shale, becoming more argillaceous below	3	
6	Coal.		6
5	Sandstone, filled with plant remains	1	
4	Fire clay.	1-2	
3	Shale, black, fissile above, more compact below filled with ironstone concretions, the basal portion contains lenticular masses of black calcareous rock	4-5	
2	Coal, sometimes partially cut out by the nodular masses above.	3-4	
1	Fire clay.	2	

More than one coal horizon, with accompanying underclay, is commonly present where the series has appreciable thickness, as in the above section. Attention has frequently been attracted to the occurrence of light colored, buff-burning clays suitable for the manufacture of pottery and formerly used in its manufacture in this part of Iowa where the lower part of the series is represented. The county is in the area included by Galpin in his exploration for satisfactory No. 1 fire clay.[42] The underclays from Van Buren and

[41] Gordon, C. H., Geology of Van Buren County: Iowa Geol. Survey, vol. 4, pp. 222-229, 1895.
[42] Op. cit., pp. 67-75.

adjoining counties tested by Galpin were found not sufficiently refractory for the manufacture of high grade refractories although a buff-colored product was secured. These clays are believed to be more common in the lower part of the series and to be more accessible in southeastern Iowa than in areas farther west.

Beds of the series have been exposed in a ravine approximately 1 mile north of Farmington in the NW¼ sec. 36, Farmington Township, (T. 67 N., R. 8 W.), in a locality where there has been considerable coal mining. Five and one-half feet of light gray sandy clay of the type tested by Galpin is exposed beneath black carbonaceous shale. It is stained yellow with limonite along cracks, has many streaks of carbonaceous material in the upper part, is quite sandy in places, and free from sand or silt and very plastic in others; it is partially indurated and almost a sandstone in places; stratification is vague. The material lies upon a black, sheeted shale and this in turn upon St. Louis limestone. This is believed to be of approximately the same quality as other light colored clays reported by Galpin.

Similar clays are also present along a ravine in the vicinity of coal mine workings about 2 miles northeast of Bonaparte in the NW¼ sec. 4, Bonaparte Township, (T. 68 N., R. 8. W.), on a farm operated in 1935 by Guy and Joe Lydolph.

Member	Description	Thickness Feet
6	Sandstone, not visible, reported to form good roof for coal mining.	2
5	Coal.	2-2½
4	Clay (underclay), light gray, plastic, slightly silty, contains pyrite nodules.	3
3	Shale, carbonaceous, thin seams of coal at bottom in some places.	5-6
2	Clay (underclay), very light gray, blue gray, dove, or gray brown, slightly silty, plastic, nodular fracture, pyrite in grains, large limestone concretions in places at top.	4½-6
1	Limestone, hard, shaly, crystalline, upper part of the St. Louis formation	3

These underclays are believed similar to others tested by Galpin, to be unsuited to the manufacture of refractories because of the presence of pyrite, and to rate as a No. 2 or No. 3 fire clay.

Clay once used in a pottery at Bonaparte, and secured approximately a mile north of the locality of the above section, in the NE¼ sec. 33, Harrisburg Township (T. 69 N., R. 8. W.), is believed to have come from this horizon.

Summarizing, it is apparent from Galpin's tests and from further exploration that buff-burning clays of fair quality occur in this county. They are not believed sufficiently free from impurities to be usable in the manufacture of refractories. They are also generally beneath considerable overburden and offer no particular advantage from the standpoint of markets or transportation.

Wapello. The Des Moines series underlies most of the county. The largest area from which it is absent is a strip up to several miles in width extending adjacent to the course of the Des Moines River Valley from the northwestern corner of the county to below Ottumwa. In this area it is absent from the following township areas:

All of Columbia except for areas of several square miles in the southwestern and northeastern corners.
An area of a few square miles in the vicinity of Avery Creek in northern Cass.
A few square miles in southwestern Richland.
A northwest-southeast strip up to a few miles wide through Center.

Other areas from which it is absent include one of a few square miles about the headwaters of Cedar Creek in Richland Township, and a strip up to two miles in width along the north border of Competime Township.

The series[43] is believed to have a maximum thickness of 250 feet in Wapello County and to average approximately 175 feet. There are many outcrops of the beds of the series along the larger valleys and many places where they are covered with only thin overburden along such valleys. Artificial exposures made for railroads, highways and ceramic plants have also been numerous. Much massive sandstone, channel in character, is known, particularly from outcrops along the Des Moines River. Black carbonaceous fissile shale makes up a considerable percentage of the shale beds near the surface. Other shales and clays, both silty and argillaceous, and of considerable range in color, are also known to make up an appreciable part of the near-surface Des Moines series.

Ceramic plants using material from the Des Moines series have at one time or another operated elsewhere in the vicinity of Ottumwa, but at present there is only the plant of the Ottumwa Brick and Tile Co. just west of the city limits. This plant has operated since 1890. Shale and clay were secured until recent years from a pit north of the plant on the east side of a small valley tributary to that of the Des Moines River in the NE¼ sec. 14, Center Township. The company is at present (1942) securing raw material from a pit on the southeast side of a small valley tributary to the Des Moines

[43]Leonard, A. G., Geology of Wapello County: Iowa Geol. Survey, vol. 12, pp. 459-471, 1902.

River in the NW¼ sec. 2, Center Township, (T. 72 N., R. 14 W.). The sections at these localities are given below:

Section: Ottumwa Brick and Tile Co., Ottumwa, Wapello County.
(Pit in sec. 14, immedately west of city limits, 1933.)

Member	Description	Thickness Feet	Thickness Inches
5	Loess and thin drift	4	10
4	Shale, light gray, silty, softened by weathering	10	
3	Shale, banded gray and red, (T), black, sheeted at bottom.	12	
2	Coal.	2	4
1	Clay (underclay), light gray, silty, carbonized plant fragments near top, upper 10 inches contain coal laminae.	8	

The workings at this pit (fig. 9) are extensive and the bottom of the unused portion lies approximately 30 feet below the above section, indicating that shale and clay were once used from that depth. In 1935 material was being secured from the south end of the pit, and only members 3, 4, and 5 of the above section were being used.

Figure 9. General view of extensive abandoned workings in the shale pit of the Morey Clay Products Company, now the Ottumwa Brick and Tile Company, Ottumwa, Wapello County.

Bricks from member 1 were buff, speckled with brown spots from the burning of pyrite; these were said to have given satisfactory service as fire brick at the plant and in bakery ovens at Ottumwa. The upper part of member 4 is stated to have once been used in the manufacture of pottery.

Section: Ottumwa Brick and Tile Co., Ottumwa, Wapello County.
(Pit in sec. 2, Center Township, northwest of Ottumwa).

Member	Description	Thickness Feet	Inches
13	Loess, with thin drift at base	6	
12	Shale, silty, weathered, contains numerous clay ironstone concretions up to 2 inches thick	6	
11	Shale, softened by weathering, silty, streaked with limonite.	5	
10	Shale (?), much like member 11, but very plastic, contains much limonite stain, may be a weathered underclay.	3	
9	Shale, carbonaceous.		3
8	Clay, (underclay), silty, plastic, limonitic seams and carbonized plant fragments numerous	1	
7	Shale, carbonaceous, plastic, notably slickensided		4
6	Clay, (underclay), silty, starchy fracture, becomes carbonaceous near top	4	6
5	Sandstone, in beds averaging approximately 8 inches thick, fairly well cemented	4	
4	Shale, gray, sandy, lower foot is dark gray to carbonaceous, grading to lighter gray above	5	
3	Coal smut.		¼
2	Clay, (underclay), silty and sandy, grading to:	2	
1	Shale, dark gray, silty, micaceous	3	

Members 12, 13, and part of 11 constitute stripping; the sandstone member 5, is also rejected. This section contains sufficient clay of an underclay type so that buff-burning ware can be produced from it. The material is trucked to the plant in Ottumwa.

There is abundant shale and clay suitable for ceramic uses in the Des Moines series of Wapello County, and there are undoubtedly many localities, determinable only by exploration, where they lie beneath thin overburden. Whether beds of undesirable sandstone, carbonaceous shale and limestone are present can also be determined only by exploration.

Washington. Only a few small outliers of the Des Moines series, none more than a few square miles in extent, are present in Washington County; one in southern Clay Township; one in northern Oregon Township; and two in Highland Township, one in the central and the other in the southeastern part. The extreme southwestern corner of Clay Township is also underlain by a few square miles of the main area of the Des Moines series. These areas, in common with the lower part of the series in southeastern counties, contain notable amounts of sandstone and underclay as well as lesser amounts of shale and coal. So far as known the shales and clays have not been used for ceramic purposes and the occurrences appear to hold no particular promise of profitable use.

Warren. The Des Moines series forms the top of the bedrock beneath all of Warren County. It outcrops[44] or is beneath only thin overburden in many places along the valleys of North, Middle and South Rivers and their larger tributaries, in places where the drift has been removed by fluvial erosion.

Sections described by Beyer and Williams[45] are given below.

Sec. 15, Allen Township.

Member	Description	Thickness Feet	Thickness Inches
8	Shale, argillaceous.	1	
7	Coal.		2
6	Shale, clay.	5	
5	Sandstone.	1	6
4	Shale, argillaceous, dark below	3	
3	Coal.		9
2	Fire clay and shale, containing nodular bands and thin seams of sandstone	14	
1	Shale, argillaceous, dark above, exposed to river.	2	

Sec. 7, Lincoln Township.

Member	Description	Thickness Feet	Thickness Inches
10	Loess.	2	
9	Coal, badly weathered.		6
8	Coal, gray, with thick bands of sandstone	10	
7	Shale, blue above and black below	4	
6	Sandstone, concretionary, calcareous.		6
5	Shale, gray to black	2	
4	Coal.	1	
3	Fire clay.	4	4
2	Sandstone, gray, heavily bedded.	1	4
1	Shale exposed.	2	6

Sec. 30, Greenfield Township.

Member	Description	Thickness Feet	Thickness Inches
6	Loess and drift, variable in thickness	10	
5	Shale, argillaceous, light.		6
4	Coal, impure and weathered.		6
3	Shale, compact above and soft below	30	
2	Sandstone, gray.		6
1	Shale, argillaceous, blue, exposed.	20	

From these outcrops, from others described by Tilton, and from mining records and well records, the series is known to consist

[44] Tilton, J. L., Geology of Warren County: Iowa Geol. Survey, vol. 5, pp. 303-358, 1896.
[45] Op. cit., pp. 490-498.

chiefly of shale with lesser amounts of clay, sandstone, coal and limestone, totalling several hundred feet.

The shales and clays of the series were at one time used in the manufacture of ceramic ware at Hartford and are at present used at Carlisle in the manufacture of heavy clay products by the Carlisle Brick and Tile Co. Raw material is secured from a pit on the east bank of North River Valley, in the NE¼ sec. 4, Allen Township, (T. 77 N., R. 23 W.). The following is an approximate section at the face of the pit.

Section: Carlisle Brick and Tile Company,
Carlisle, Warren County (1935).

Member	Description	Thickness Feet	Thickness Inches
8	Loess.	0-3	
7	Drift.	0-3	
6	Shale, gray, laminated.	4	
5	Coal and carbonaceous shale.		4
4	Clay (underclay), light gray but streaked with yellow brown on weathered face, silty, plastic.	5	
3	Shale, gray, very silty and sandy, almost sandstone in places.	3	
2	Shale, gray, laminated, silty, contains irregular calcareous concretions.	6	
1	Covered, to river level.	50	

Coal mined nearby evidently lies within the covered part of the above section and is believed underlain in turn by light gray underclay.

The raw mix is in the proportion of approximately one-third of member 4 and two-thirds of 2 and 3. The material is said to handle well in auger machines and driers and is burned at 1960° F.

Summarizing, there is an abundance of shale and clay suitable for the ceramic industry in the Des Moines series in Warren County, and there are many places on the sides of the deeper valleys where it lies beneath comparatively thin overburden.

Wayne.[46] The Des Moines series forms the top of the bedrock beneath the entire county. The drift cover is thick, however, and the only outcrops, chiefly limestone, are in the northeastern corner. From well records and coal mining operations, however, the series is known to contain an abundance of shale and underclay. They are everywhere so thickly covered with drift that their use is not considered a likely one.

Webster. The exact boundaries of the area of the Des Moines series in Webster County and the extent to which it is overlain by

[46]Arey, M. F., Geology of Wayne County: Iowa Geol. Survey, vol. 20, pp. 213-222, 1910.

the Fort Dodge gypsum beds are not accurately known because of the considerable thickness of glacial drift over most of the county and the absence of outcrops except along the valley of the Des Moines River. The series is believed to form the top of the bedrock of most of the county, but is absent from a strip a mile or more in width adjacent to the Des Moines River and the lower part of some of the larger tributaries from the northern boundary to a point a few miles south of Fort Dodge. It is thus absent from eastern Deer Creek Township, northwestern and southwestern Badger, northwestern Douglas, and eastern Cooper. It is also believed absent from an area of a few square miles in southern Elkhorn and northern Clay Townships.

The Des Moines series is overlain by gypsum beneath an area of several square miles in the vicinity of Fort Dodge, which includes southeastern Douglas, southwestern Fulton and northwestern Elkhorn; and from a larger area which includes much of central and southwestern Cooper; and small areas along the western side of Colfax and the northern side of Otho Townships.

The series[47] is exposed only along the Des Moines River and some of its larger tributaries south from the vicinity of Fort Dodge. Only the lower part of the series is present, with thickness of as much as 100 feet. Much information regarding the series has been obtained from the natural exposures, coal mining and clay working operations and well records. The series here includes thick beds of shale and underclay, as well as much sandstone and coal, and some limestone. The sections at the shale pits of the ceramic plants at present operating, of which there are four, serve to illustrate the materials present and used by the ceramic industry.

The three plants in the vicinity of Fort Dodge are the Vincent Clay Products Co., with plant and pit a few miles southeast of Fort Dodge on the east side of Des Moines River Valley in the SW¼ sec. 6, Pleasant Valley Township, (T. 88 N., R. 28 W.); the Johnston Clay Works with plant and shale pit approximately 4 miles southeast of Fort Dodge on the west side of Des Moines River Valley in the SW¼ sec. 8, Otho Township (T. 88 N., R. 28 W.); and the Kalo Brick and Tile Co., with plant approximately 5 miles southeast of Fort Dodge on the west side of Des Moines River Valley in the SE¼ sec. 17, Otho Township and the pit across the river in the NE¼ sec. 17, Pleasant Valley Township (T. 88 N., R. 28 W.). These sections, though not located more than a few miles apart, have not been definitely correlated because of the lack of persistent key beds.

[47]Wilder, F. A., Geology of Webster County: Iowa Geol. Survey, vol. 12, pp. 83-99, 1902.

Section: Vincent Clay Products Co.,
Fort Dodge, Webster County.

Member	Description	Thickness Feet	Inches
16	Till.	0-15	
15	Gypsum in irregularly shaped erosion remnants, (fig. 10).	0-8	
14	Sandstone, red and brown, conglomeratic toward top, calcareous.	0-3	
13	Shale, gray and buff, with bright red streaks, soft from weathering.	4	6
12	Shale, very silty, banded light gray and red.	1	6
11	Sandstone, dull red, argillaceous, softened by weathering, grades to:	1	3
10	Shale, light gray, laminated.	1	
9	Shale, dark gray, laminated, notable number of clay ironstone concretions.	2	8
8	Clay (underclay), gray, coal smut at top.		4
7	Shale, dark red.	1	6
6	Shale, dark gray, laminated.		6
5	Shale, silty, nodular fracture.		4
4	Shale, argillaceous, dark slate blue and gray, fissile, particularly toward bottom, contains numerous calcareous concretions approximately in middle; streaks of crumbly red, sandy clay. (T)	10	8
3	Clay (underclay?), gray buff, angular fracture, no lamination. (T)	1	9
2	Shale, laminated red and light gray. (T)		3
1	Sandstone, white, noncalcareous, slightly cross-bedded.	4	

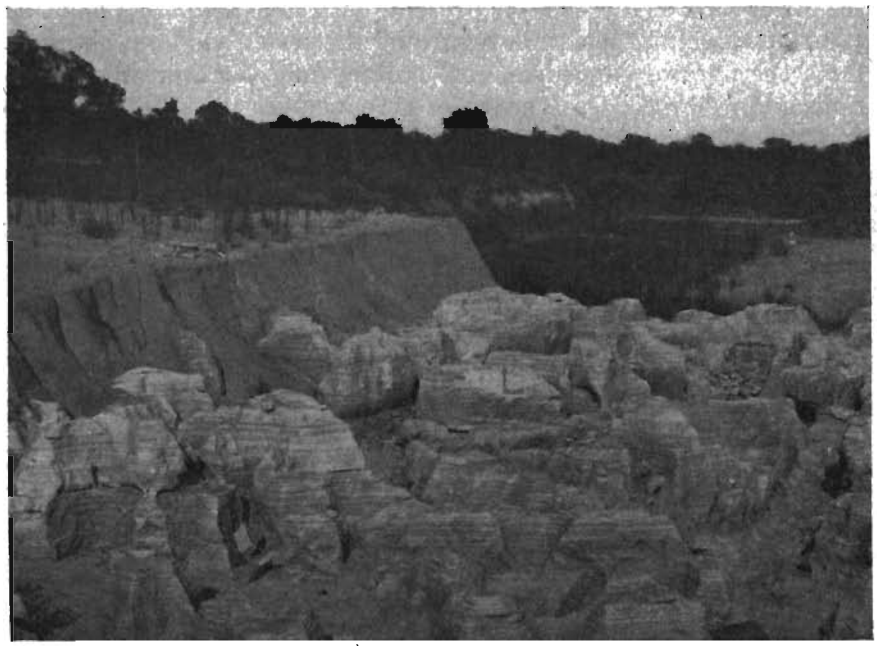


Figure 10. Gypsum above the shale pit of the Vincent Clay Products Company, near Fort Dodge, Webster County.

Abandoned parts of the pit in 1932 showed 1 foot of coal above member 2 of the above section, in turn overlain by black sheeted shale. The described section contains a large number of members for the thickness involved. These are based largely upon color differences which are very clear, since the pit is operated by a planing machine, but these shale members do not differ appreciably in ceramic properties. The upper part of the section exposed in 1942 is somewhat different from that described above since the pit has been extended north and east, and is thinner and more affected by weathering. In 1935 members 2 to 13 inclusive were being used in the mix.

During the past two years the company has been using a No. 3 fire clay or potter's clay, secured from a drift mine in the hillside north of the plant, in the production of a cream- to buff-colored ware. The shale from the pit and the clay from the mine are treated by the same methods,[48] are considered equally plastic, and are burned at approximately 2000° F., with total shrinkage of 14 percent.

The section at the pit of the Johnston Clay Works is believed to lie at approximately the same horizon as that of the Vincent Clay Products Co.

Section: Johnston Clay Works, Inc.,
Fort Dodge, Webster County. (1933)

Member	Description	Thickness Feet
6	Sand and gravel, terrace deposit	10
5	Drift, chiefly till.	0-10
4	Gypsum, irregularly shaped residual masses	0-6
3	Shale, dark gray, silty, plastic when wet, fissile when dry, contains streaks of sandy hematitic ocherous material in part weathered to limonitic clay and sand	2
2	Shale, dark gray, fissile when dry, abundant streaks, laminae and thin lenses of sandy, hematitic, ocherous material, similar to those of member 3; hematite in part weathered to limonite, lenses of light gray shale up to three inches thick. (T)	11
1	Shale, light gray, irregularly streaked with hematitic lenses, more silty than member 2. (T)	8

The differences between the members of the foregoing are probably minor from the clay worker's viewpoint. Working at approximately the same level, the section today (1942) is believed to differ somewhat from the above. This is to be expected since the original character and thickness of members may be expected to vary somewhat, the effect of weathering varies, the pit face may be higher or lower in the section, and faults may cross the area.

[48]Communication from Mr. O. J. Whittemore.

In 1942 the base of the pit face was somewhat lower than in the section described, so that 4 inches of coal and carbonaceous shale overlying 6 inches of underclay were exposed. Two faults along which there had been movement of a few feet, were also apparent, although not clearly exposed. The sandstone (member 1) of the Vincent Clay Products Co. section is believed to lie below the section of the Johnston pit.

In 1933 members 1, 2 and 3 of the section were being used in the plant mix. In addition, material from an opening east of the above and nearer the plant, was added to reduce shrinkage in the product. It was a light gray and sandy shale, with the hematitic and orcherous streaks of the foregoing section, believed to be a weathered phase of member 2. At present[49] (1942) approximately 50 percent each of members 1, 2 and 3 together, are used. The ware is burned at 2100° to 2300° F., with shrinkage of approximately 12 percent.

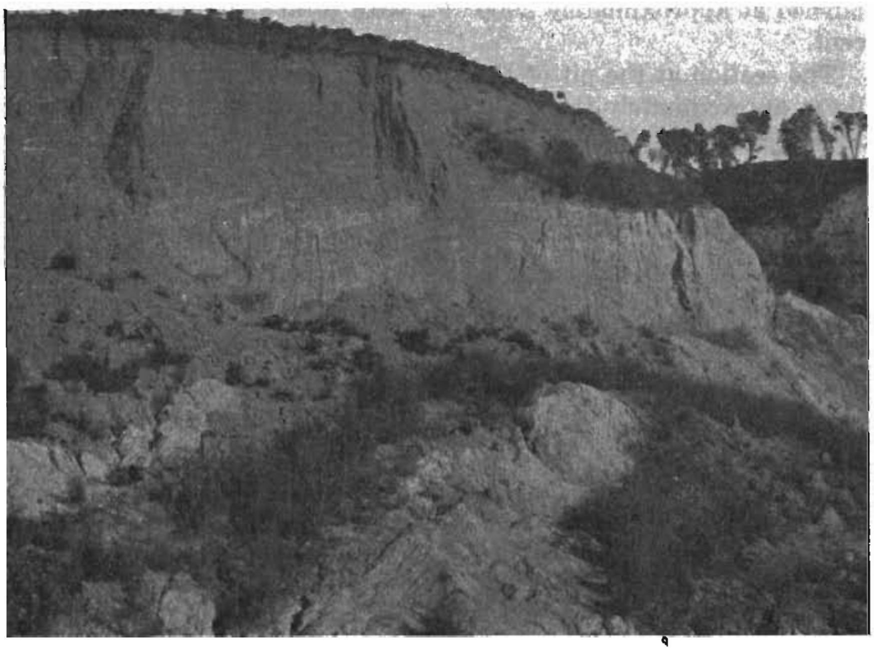


Figure 11. Thick glacial drift and channel sandstone in the shale pit of the Kalo Brick and Tile Company, Kalo, Webster County.

The section at the pit (fig. 11) of the Kalo Brick and Tile Co., although but approximately a mile to the southeast, bears little resemblance to that of the Johnston Clay Works.

[49]Communication from Mr. G. L. Johnston.

Section: Kalo Brick and Tile Company,
Kalo, Webster County. (1933)

Member	Description	Thickness Feet	Inches
5	Drift, fresh to weathered	0-30	
4	Sandstone, channel, light gray, micaceous and argillaceous, readily disintegrates by weathering, lower part contains black fragments and grains evidently derived from underlying shale, red and purplish red ferruginous bands near top, more resistant to weathering, cross-bedded with dips up to 20 degrees, contact with underlying shale not visible but apparently highly irregular.	0-10	
3	Shale, silty, red and gray, somewhat carbonaceous, with concretions and septaria, thickness varies because of irregular upper surface in contact with overlying sandstone. (T)	10-20	
2	Clay (fire clay?), light gray and gray brown, no coal visible above.	6	4
1	Shale, black with organic matter, plastic, conchoidal fracture, almost like that of cannel coal, contains strikingly large number of flattened disc-like clay ironstone concretions and septaria up to 2 feet in diameter, weathered a purplish red and contain pyrite and calcite in the veins, member is partly covered by slope wash. (T)	30	

Members 1, 2 and 3 were being used in the plant mix in 1933. The concretions were separated by hand and had accumulated in large numbers on the floor of the pit. Drift overburden was being removed by hydraulic methods.

By 1942, with extension of the pit face to the east into the side of the valley, the thickness of the channel sandstone (member 4) had increased to approximately 15 feet. Septaria and other concretions were no longer present in abundance in members 1 and 3. Lenses of weakly cemented white sandstone, up to a few feet thick, had made their appearance in the lower part of member 1 which however was not worked to the same depth as in 1933.

At present (1942) the different members are mixed in proportions such as will produce the desired result. A mix[50] consisting of 15 percent of member 1, 35 percent of member 2 and 50 percent of member 3 is used for much of the ware. Kilns are burned at 1850-2050° F.

Raw material was secured prior to 1918 from a pit on the west side of the river, probably abandoned because of increasing thickness of overburden. Shale is at present moved across the river to the plant by aerial tramway.

The southernmost plant of the county is that of the Lehigh Sewer

[50]Communication from Mr. G. E. Schnurr.

Pipe Co., approximately a mile southwest of Lehigh in the valley of Crooked Creek, with pit on the north side of the valley in the NW¼ sec. 13, Sumner Township, (T. 87 N., R. 28 W.).

Section: Lehigh Sewer Pipe Company,
Lehigh, Webster County. (1933)

Member	Description	Thickness Feet	Inches
13	Drift, principally till, unweathered in lower part	0-30	
12	Shale, argillaceous, deep red to yellow brown and maroon.	3	6
11	Shale, light gray, silty.		6
10	Shale, yellow gray, silty	3	6
9	Shale, argillaceous, deep red or maroon, irregular to fissile fracture.	2	6
8	Shale, sandy, massive, finely banded light and dark gray, almost an argillaceous sandstone.	5	
7	Shale, argillaceous, finely banded yellow, gray, dull red, dull purple, fissile.	4½-5	
6	Clay (underclay?), sandy, light gray, irregular fracture, no coal smut visible above		6
5	Clay (underclay?), sandy, dull purple, irregular fracture.	1	
4	Shale, argillaceous, buff, fissile.	4	
3	Sandstone, shaly, gray.	3	
2	Sandstone, light gray, weakly indurated, partly calcareous.	3	
1	Shale, buff at top, grading to carbonaceous below	6	

All of this section was being used in the plant mix except the indurated parts of members 2 and 3. This section contains shale beds which are quite unlike in color and to a lesser degree in content of silt and sand. These differences, as elsewhere, are not appreciable in terms of ceramic properties. In any case the properties of the finished product may be controlled by proper admixture of material from the different horizons which may vary somewhat in plasticity, amount of shrinkage in the ware, and in other properties.

This vicinity has been the scene of a ceramic industry for several decades, and the side of the valley of Crooked Creek has been worked for shale and clay for many hundreds of feet. Because of the steepness of the valley sides the thickness of the drift overburden increases rapidly in short distances, so that any clay pit may expect to encounter this difficulty as it is extended into the valley side. The abundance and desirability of the raw material are apparent however from the history and extent of the industry here.

Summarizing, the shales and clays of the Des Moines series in Webster County contain an abundance of shale as well as, in some places, of underclay capable of producing a buff ware. They lie reasonably close to the surface on the sides of the deeper valleys such as that of the Des Moines River and of the larger tributaries in their lower courses. The difficulty of increasing thickness of overburden is likely to arise as the workings from which shale and clay are secured is extended into the valley sides. The abundance and good quality of the material for the manufacture of heavy clay products is apparent from the history of the industry in the county.

Wright. The Des Moines series forms the top of the bedrock beneath heavy glacial drift in a belt extending through the southern townships. Boundaries are not certainly known because of the thick blanket of glacial drift and lack of outcrops, but the series is thought to underlie the following township areas:

The southwestern third of Eagle Grove.
All of Troy.
Woolstock with the exception of a narrow strip up to a mile in width along the northern boundary.
Wall Lake with the exception of a strip 2 miles long along the northern boundary.

The beds do not outcrop and little has been learned regarding them from drilling records. While the series in this area is believed to contain an abundance of ceramic shales and clays, somewhat resembling those of the vicinity of Fort Dodge, they are inaccessible because of the generally thick overburden.

Summary. Shales and clays of the Des Moines series. Wherever the Des Moines series is present in appreciable thickness there is included a high proportion of shale and a smaller proportion of underclay, buff-burning and of somewhat refractory properties but still unsuited for high grade products. The lower 200 feet of the series is thought to contain more sandstone and underclay than that higher in the section. The shale and underclay are suited to the manufacture of a wide range of heavy clay products.

Because of the relatively thick mantle of the area north of Des Moines, beds of the series are generally inaccessible except in a relatively few places where deep valleys have been incised to their level. Most of the southern counties have many places where they are accessible along valleys. In the southwestern part of the State they are inaccessible for all practical purposes because of the thick mantle. In the southeastern part they are again rather widely exposed or near the surface but many of the exposures are of sandstone and the deposits are comparatively thin.

SHALES AND CLAYS OF THE CRETACEOUS SYSTEM

The topmost bedrock in northwestern Iowa and in much of the western and southwestern part of the State is that of the Creaceous system.

Extent. The extent of the area underlain with the system is not certainly known because of the lack of outcrops. The solid Cretaceous area of northwestern Iowa is believed to include all or some part of Buena Vista, Cherokee, Clay, Crawford, Dickinson, Emmet, Harrison, Ida, Kossuth, Lyon, Monona, O'Brien, Osceola, Palo Alto, Plymouth, Pocahontas, Sac, Sioux and Woodbury Counties.

Another large irregularly shaped area of more than 1200 square miles extent underlies parts of Adair, Audubon, Calhoun, Carroll, Cass, Greene, Guthrie and Sac Counties. Another area of several hundred square miles extends irregularly over Adams, Cass, Mills, Montgomery and Pottawattamie Counties. Other small isolated areas are believed present in Adams, Kossuth, Montgomery and Page Counties. There may be other small areas elsewhere beneath the mantle, and it is recognized that areas mapped as isolated may be connected, and that areas mapped as solid may have many places from which the system is absent. The thickness ranges up to several hundred feet, but over much of the area is believed to be less than 100 feet.

General stratigraphy and structure. The system in Iowa is made up of interbedded clastic and limy sediments, including soft buff and white sandstone and siltstone, buff conglomerate ("peanut gravel"), gray and white sandy and silty shale and clay, calcareous clay and marl, and soft limestone and chalk.

The northwestern Iowa area, believed to include the Dakota, Graneros, Greenhorn and Carlile formations, contains considerable thicknesses of shaly and limy beds in the upper part, with the sandy and gravelly beds of the Dakota at depth. The other areas are comprised chiefly of weakly cemented sandstones and conglomerates and lesser amounts of gray clay and shale, all of the Dakota formation.

The detailed stratigraphy of the system is not well known over much of the area, because of the generally thick mantle of glacial clay and loess, and the absence of outcrops. Well records have furnished much of the available information.

The beds rest unconformably upon the underlying rocks and have a regional dip of a few or several feet per mile to the northwest. Reversals of the dip are probably present in places.

Uses. Shale and clay of the system in Iowa have proven suitable for the manufacture of ceramic wares, particularly of heavy clay products. They have been used at several places, but at present are used only in the vicinity of Sioux City.

The occurrence and relations of Cretaceous shales and clays will be described for only a few of the counties where they occur. Those selected are counties where the beds are reasonably well known, or have been used, or have had attention attracted to them because of the known occurrence of shale and clay.

Adams. Beds of the Dakota formation form the top of the bedrock beneath areas totalling many square miles in the western part of the county, including the following township areas:

The northwestern part of Lincoln.
Central, western and southern Douglas.
Northern Nodaway.

There are many outcrops,[51] some of them meager, particularly in Douglas Township. Wood recognizes two units, "a lower one consisting almost entirely of fine-grained sandstone, and an upper one of coarser sandstone and bright-colored clay." Other outcrops are described as containing clay with a high content of silt, and siltstone. A section from "south of the west quarter-section corner of section 19 Douglas township," believed to present the approximate average thickness, is given below:

Section: Douglas Township.

Member	Description	Thickness Feet	Thickness Inches
4	Till, dark gray, unoxidized, unleached, with scattered lime concretions, and definite layer of concretionary lime marking contact with the bed below.	5	
3	Sandstone, brown, coarse-grained, some lenses conglomeritic, grains of quartz, iron oxide, and reddish brown oxidized shale.	8	
2	Shale, silty, and siltstone, light gray to drab, massive, with brown ferruginous concretions and thin layers, and a few thin lenses of sandstone. Much of the ferruginous concretionary material is derived from or surrounds plant fragments.	33	
1	Sandstone, buff, medium-grained; a strong massive ledge.	5	

The light-colored shales and clays, some silty and some lacking in silt, apparently are present in thicknesses of many feet in the Dakota areas of Adams County and presumably in adjoining Montgomery, Pottawattamie and Cass, but they are so interstratified with thick beds of sandstone and conglomerate that they are not believed to have potential value for industry of any size. It is believed that some at least are buff-burning and somewhat refractory, and these might be used for small scale operations. Depth of

[51] Wood, L. W., Geology of Adams County: Iowa Geol. Survey, vol. 37, pp. 316-321, 1941.

overburden, in part sandstone, makes the shale, believed suitable for heavy clay products, of but little potential value.

Carroll. Beds of the Cretaceous system are believed to form the top of the bedrock beneath most of the eastern and northern parts of the county.[52] They are known from well records and from a few exposures along the Middle Raccoon River, the North Raccoon River, and Purgatory Creek.

Outcrops have been described as consisting principally of sandstone and conglomerate, with a smaller amount of light gray clay in the form of beds in thin seams. Large blocks of clay believed to have come from such Cretaceous occurrences in the area have been found in the drift. From this it seems likely that deposits of this clay may exist in the rocks beneath the drift, possibly at the top. They may well be thin and irregular in thickness if similar in structure to light gray clay elsewhere in the Cretaceous of this part of Iowa.

Cass. Beds of the Dakota formation are believed to form the top of the bedrock beneath the mantle of a few townships in the northeastern townships and several in the southwestern townships. From outcrops and well records it is known that the Dakota of the county is almost entirely sandstone, although thin clay beds are present in some places.[53] The clay is thought to be like that found near Red Oak, which burns to a buff color and is refractory. Judging by the known occurrences it does not exist in sufficient quantity or sufficiently free of overburden to be considered a potential resource.

Greene. Beds of the Dakota formation outcrop in Greene County and are believed to form the top of the bedrock of the western tier of townships. An occurrence of light gray clay northeast of Scranton in the NE¼ sec. 26, Cedar Township, (T. 84 N., R. 32 W.), has attracted attention during the past decade or two. The clay is in scattered exposures of Cretaceous rocks on both sides of a small valley tributary to that of the Raccoon River. The following is an approximate section of the exposures on the north side of the valley:

Member	Description	Thickness Feet	Inches
3	Glacial clay.	0-75	
2	Sandstone, bright orange, contains clay fragments and quartz pebbles		3
1	Clay, light gray mottled with white, silty, irregularly jointed, conchoidal fracture, plastic, slakes readily, joint surfaces stained yellow with limonite.	4-5	

[52]Bain, H. F., Geology of Carroll County: Iowa Geol. Survey, vol. 9, pp. 73-75, 1899.
[53]Tilton, J. L., Geology of Cass County: Iowa Geol. Survey, vol. 27, pp. 203-209, 1917.

The following is an approximate section of an outcrop on the side of the valley and a few rods from the one given above:

Member	Description	Thickness Feet Inches
4	Glacial clay.	0-75
3	Sandstone, bright orange, varies greatly in cementation, in part almost black with limonite, cross-bedded.	10-12
2	Conglomerate, orange, irregularly bedded, made up of quartz pebbles and flat pieces of white clay up to 6 inches long.	0-3
1	Sandstone, light yellow, soft, contains flat clay fragments up to 6 inches long in the upper part.	4

There are scattered exposures of conglomeratic sandstone and one of white clay nearby, and other outcrops of sandstone along the valley down to its confluence with that of the Raccoon River. Any other occurrences of white clay in this distance can only be rather small since otherwise they would show to some extent on the valley side.

Small amounts of the clay were used satisfactorily on a very small scale in the manufacture of art pottery by the Ames Art Pottery Co. of Ames and by a pottery company at Fort Dodge. The material is suited to the manufacture of cream or buff products such as pottery. These deposits are obviously so limited in quantity that they could not furnish the material for any sizeable industry. Other deposits of similar clay may be present elsewhere in the Dakota of Greene or surrounding counties. It is thought likely that any such deposits would be no more extensive than those described above.

Guthrie. Beds of the Dakota formation form the top of the bedrock beneath the mantle of most of Guthrie County with the exception of the eastern tier of townships. It is absent from strips up to approximately a mile wide along the course of the valley of the Middle Raccoon in Victory, western Highland and eastern Orange Townships; that of Brushy Fork in northern Seeley Township; that of the South Raccoon in southwestern Jackson and eastern Valley Townships; and that of Beaver Creek in northern Beaver Township.

The mantle of the county is generally thick but beds of the formation are exposed[54] in places along both branches of the Raccoon River, Brushy Fork, Beaver Creek, Spring Branch and small tributaries of these streams. Bain reports thicknesses of as much as 100 feet. Most of this is sandstone and conglomerate of varying

[54]Bain, H. F., Geology of Guthrie County: Iowa Geol. Survey, vol. 7, pp. 451-459, 1897.

degree of induration, but clay (or shale) up to 17 feet thick is interstratified in some places. Twenty feet of clay occurring near the fair grounds is stated by Bain to contain bands of sand. It is believed that some of this clay or shale is similar to that found irregularly interstratified with sandstone and conglomerate in outcrops in other counties which have been inspected in the course of this investigation. It is thought that while this clay is of relatively high quality it does not exist in Guthrie County in sufficient thickness, or sufficiently free of overburden or interstratified soft sandstone and conglomerate to make it a potential resource. Almost all of the outcrops are predominantly sandstone or conglomerate or both, and Bain states that the shale and clay members are the least widely distributed.

Montgomery. The Dakota formation is believed to form the top of the bedrock beneath most of Montgomery County with the exception of the southeastern corner and most of the western half. It is absent from the greater part of West, Garfield, Jackson and Scott and from much of Lincoln, Sherman, Red Oak and Grant Townships.

There are numerous outcrops[55] in a number of places along the larger valleys, and the formation is also known from well records. It is believed to average a few score feet in thickness. Conglomerate, sandstone, and shale or clay are present, and of these, sandstone is in the greatest amount and most widespread. The overlying mantle of glacial clay and loess ranges up to as much as 160 feet in thickness and is thought to average approximately 75 feet.

The shale or clay has thus far been found below the sandstone or in lenses within it. In some of the occurrences it is a light cream, drab or gray in color, has a conchoidal fracture, slakes easily, and is plastic when wet. It burns to a light colored product at a high temperature and is therefore suitable for use in the manufacture of pottery and buff face-brick. Material from the formation was at one time used in the manufacture of pottery and by brick plants in the vicinity of Red Oak, but the pits from which it was secured have long since become obscured through disuse.

Two localities where the material outcrops were examined, one of them near the site of a pottery which once operated southeast of Red Oak. An approximate section of nearby exposures (fig. 12) on a small tributary of the Nishnabotna River in the SW¼ sec. 27, Red Oak Township, (T. 72 N., R. 38 W.), is given below.

[55]Lonsdale, E. H., Geology of Montgomery County: Iowa Geol. Survey, vol. 4, pp. 412-427, 1895.

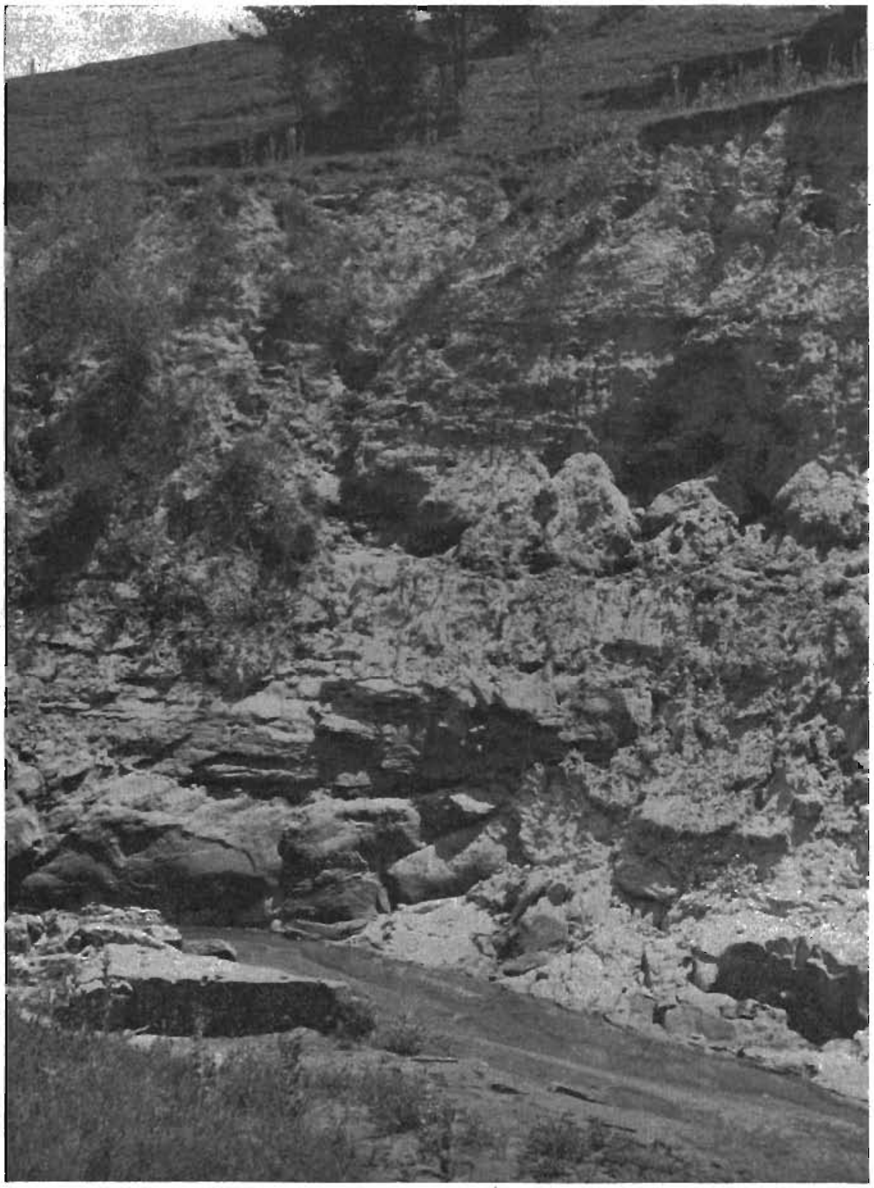


Figure 12. Interbedded Cretaceous sandstone and clay southeast of Red Oak, Montgomery County.

Member	Description	Thickness Feet	Inches
6	Sandstone, weathered.	3	
5	Clay, gray, with numerous interbedded sandstone layers.	6	
4	Sandstone, cross-bedded, containing layers of light gray clay up to several inchs thick, and fragments of clay in places.	6	
3	Sandstone, ferruginous, conglomeratic, containing many clay fragments.	2	
2	Clay, white and gray, sandy, plastic. (T)	2	
1	Sandstone, white.	2-4	

Scattered outcrops nearby are sufficiently different from the above to show that the section changes within short distances. Ceramic tests on member 2 of the above section, reported in the Tests on Iowa Shales and Clays, show it to be a highly refractory, light buff-burning clay. It is in such small quantity, so uneven in distribution, and lies beneath such heavy overburden that its exploitation on a sizeable scale would not be profitable. Similar material secured from exposures near the present waterworks in Red Oak, probably was used by the pottery company which once operated in that city.

Some years ago attention was attracted to an occurrence of light-buff clay on the east side of the valley of the Nishnabotna River in the SW¼ sec. 17, Grant Township, (T. 71 N., R. 28 W.), on land owned by Mr. Pim. The clay is present beneath the bottom of a gravel pit of weakly cemented Cretaceous conglomerate, which had been removed to the level of the clay. The lower 5 feet of the conglomerate contains clay fragments in the form of slabs or blocks up to several feet in length and several inches in thickness. The buff clay is a few feet thick and is underlain by a similar clay, dull red in color. Presence of the deposit for a few hundred feet along the valley is indicated by a line of springs and seeps at about the same level. The clay is overlain by at least a few score feet of conglomerate and mantle. The thickness of the clay has not been determined, although beds of the Missouri series are believed to lie not many feet below the bottom of the pit. The clay greatly resembles in appearance that from the locality southeast of Red Oak, and if it resembles it in structure it is uneven in distribution and not more than a few feet thick. This clay also may be buff-burning and refractory, but its questionable thickness and its occurrence in association with the conglomerate and beneath thick overburden makes it of small potential value. This is also believed to be the case for any other occurrences of shale or buff-burning clay in the Dakota formation of Montgomery County.

Plymouth.[56] Beds of the upper part of the Cretaceous system as it is represented in Iowa are believed to form the top of the bedrock beneath all of Plymouth County. It is generally covered with mantle, much of it loess, scores of feet thick, and outcrops are confined almost entirely to the valley of the Big Sioux River and the lower parts of the larger tributary valleys. Particularly notable outcrops are at the confluence of the valley of Broken Kettle Creek with that of Big Sioux. The beds are also known from the numerous wells drilled through them to the Dakota aquifer in the lower part.

Sandstone is believed to predominate in the lower part of the system in Plymouth County, shale in the middle, and chalk and marl in the upper part. Some lignite is also present. Because of the slight regional dip to the northwest the lowest beds exposed are in the southern part of the area, but even these are in the upper part of the section.

The section described by Bain north of the confluence of Big Sioux and Broken Kettle Valleys in sec. 32, Sioux Township, (T. 91 N., R. 48 W.), is given to show the character of the Cretaceous in this county:

Member	Description	Thickness Feet	Thickness Inches
6	Limestone in thin beds, interstratified with 4 to 10 inches of chalk.	90	
5	Shale, buff, sandy, contains thin layers of sandstone and ferruginous concretions.	30	
4	Shale, dark blue to drab, fine-grained, argillaceous.	10	
3	Sandstone, fine-grained, calcareous, light buff to white.	15	
2	Lignite.	1	6
1	Fireclay, white to light gray, only slightly exposed, found by digging.	6	

Bain believes the fire clay suitable for the manufacture of fire brick, but from the chemical analyses cited it would appear that they would not be as suitable as clays used elsewhere in the manufacture of refractory products.

This clay lies at approximately the river level; it has excessive overburden and a poor roof for drift mining. Member 4 is suitable for the manufacture of heavy clay products but also lies beneath excessive overburden. It is thought to lie beneath similar thicknesses elsewhere and thus to have but little potential value as a clay resource.

Pottawattamie.[57] Beds of the Dakota formation are at the top

[56]Bain, H. F., Geology of Plymouth County: Iowa Geol. Survey, vol. 7, pp. 328-335, 1897.
[57]Udden, J. A., Geology of Pottawattamie County: Iowa Geol. Survey, vol. 11, pp. 233-242, 1901.

of the bedrock beneath the southeastern townships of Pottawattamie County. They are thought to underlie all of Center, Wright, Grove and Waveland; and parts of Valley, Lincoln, Belknap and Macedonia Townships. Boundaries of the formation are not definitely known because of the thick cover of glacial clay and loess, estimated to average 140 feet in thickness beneath the uplands.

The formation is known from a few outcrops and from well records. The outcrops are mostly sandstone overlain by shale, and well records show a similar section. Shale outcrops in the NE¼ sec. 36, Wright Township, (T. 75 N., R. 38 W.), and sec. 1, Waveland Township, (T. 74 N., R. 38 W.). The general section given for the locality by Udden and believed to represent approximately the maximum thickness in the county is:

Member	Description	Thickness Feet	Inches
3	Clay, grayish white or dark, weathers yellow and red, occasional streaks of fine sand and dark carbonaceous seams, contains concretionary lumps of siderite.	37	
2	Clay and fine sand.	3	
1	Sandstone, fine-grained, uniform white or gray, partly cross-bedded.	42	

Sac.[58] Beds of the upper part of the Cretaceous system as it is represented in Iowa form the top of the bedrock of all Sac County. The mantle of glacial clay and loess averages a few score feet in thickness, and outcrops of the bedrock are present only along Raccoon River in the vicinity of Grant City. Sandstone, shale, clay and chalk are present in the outcrops. The clay considered most promising as a ceramic material has a thickness of 15 feet and is described by MacBride as a fissle, drab-colored clay resembling fire clay in appearance. This material is said to have at one time been considered for use in brick manufacture, but so far as known was never used. The shales are undoubtedly suitable for heavy clay products manufacture and some of the clay may be of the buff-burning sort found elsewhere in the system in other western counties, but the heavy overburden would prevent their use by any sizeable industry.

Sioux.[59] The beds of the Cretaceous system form the top of the bedrock beneath all of Sioux County. The mantle, drift and much loess, averages approximately 75 feet in thickness. Outcrops of the bedrock, few in number, are known only from the western part of

[58]MacBride, T. H., Geology of Sac and Ida Counties: Iowa Geol. Survey, vol. 16, pp. 526-531, 1906.

[59]Wilder, F. A., Geology of Sioux County: Iowa Geol. Survey, vol. 10, pp. 108-117, 1900.

the county along the valley of Big Sioux River. Shales are also exposed or close to the surface at two other localities, one in sec. 22, Logan Township, (T. 94 N., R. 48 W.), the other in sec. 12, Buncombe Township, (T. 95 N., R. 48 W.). Some knowledge of the system in the county has also come from the records of wells drilled to the Dakota sandstone.

Shale, limestone and shale horizons occur in order above the sandstone. The upper shale is described by Wilder as an argillaceous, noncalcareous fissile variety, principally slate gray color but in part with shades between red and black. It contains gypsum but not in quantity sufficient to interfere with its use. The lower shale is harder and darker, grades into the limestone above, and is more calcareous. The upper shale was found suitable for use in the manufacture of bricks in a plant at Hawarden.

Woodbury.[60] Beds of the Cretaceous system form the top of the bedrock beneath all of Woodbury County. The mantle of drift and loess averages at least a few score feet and outcrops of the bedrock are present only along the bluffs of the Missouri River in the vicinity of Sergeant Bluff and in Sioux City, and along the bluffs of the Big Sioux River north of Sioux City. Records of wells to the Dakota have also contributed to knowledge of the system in the county.

Sandstone, shale, and limestone make up the series which reaches a thickness of approximately 500 feet at Sioux City. Owing to the regional dip, higher and higher beds are present north from Sergeant Bluff along the valley of the Missouri River.

The lower part, the Dakota, has sandstone and shale, with shale predominating near the bottom, in outcrops at Sergeant Bluff. Shale beds predominate higher in the section, as at Sioux City. Limestone and chalk are more abundant in the still higher part as shown by outcrops north of Sioux City.

The shales and clays have been used in the ceramic industry at Sioux City and Sergeant Bluff for many years.

The shale pit of the Sergeant Bluff plant of the Sioux City Brick and Tile Co. is northeast of Sergeant Bluff in sec. 30, Woodbury Township, (T. 88 N., R. 47 W.). Shale and clay have been taken from a distance of several hundred feet along the bluff, and in 1934 were being secured from an opening northwest of the plant (fig. 13).

[60]Bain, H. F., Geology of Woodbury County: Iowa Geol. Survey, vol. 5, pp. 242-298, 1896.

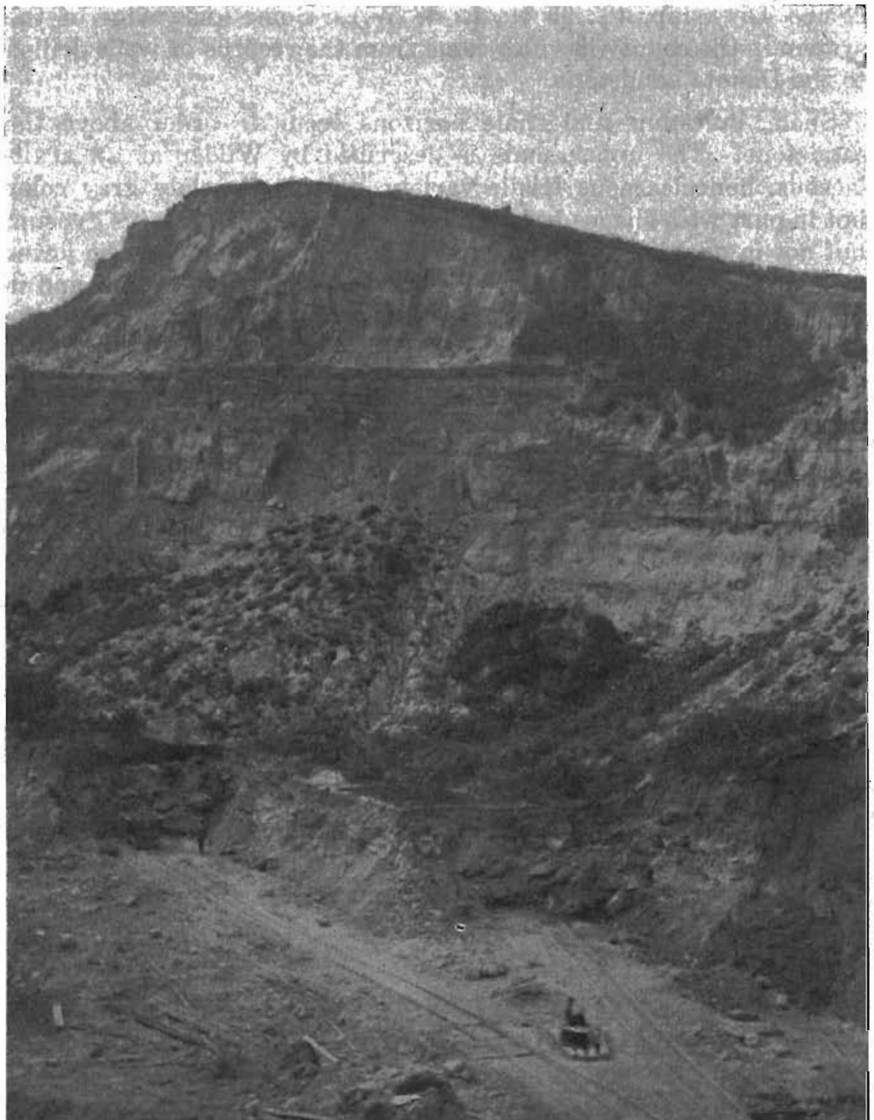


Figure 13. Shale pit of the Sioux City Brick and Tile Company, at Sergeant Bluff, Woodbury County.

Section: Sioux City Brick and Tile Co.,
Sioux City, Woodbury County, (1933)

Member	Description	Thickness Feet Inches
6	Loess.	4-30
5	Sand.	1-4
4	Sandstone, light brown, well defined joints, massive at bottom, stratified toward top.	0-20
3	Shale, sandy, contains many carbonaceous seams, about 2 feet lignite near top, is in part a shaly sandstone.	0-25
2	Shale, light gray to dove gray, in part argillaceous, but mostly containing silt, stratification indistinct, joints irregular and dipping 45 degrees or less, contains scattered plant impressions and fragments, particularly numerous in a zone near the top. (T)	46
1	Shale, gray and gray brown, silty, a zone near the middle contains much carbonaceous material. (T)	10

Members 1, 2 and 6 were the basis of the raw material being used in 1935. Where members 3 and 4 were of minor thickness and 5 absent the entire section was used.

The shale burns to a buff color and a hard ware can be produced from it. Loess is included in order to lower the burning temperature somewhat.

Shale and clay were formerly secured from a pit northeast of the plant and several rods from the present one. The exposures here are higher than those described above.

Section: Abandoned Pit at Sergeant Bluff,
Woodbury County.

Member	Description	Thickness Feet Inches
3	Sandstone, brown, prominent jointing, 1 foot near the middle is hard and dark brown with limonite.	25
2	Shale and shaly sandstone interbedded, in part strongly cemented with limonite.	3
1	Shale, argillaceous and sandy, dark gray from carbonaceous matter, grading to thin lignite beds toward the top.	23

Heavy clay-products plants have operated for many years in the Riverside district in the western part of Sioux City. Recently shale and clay have been secured from the east side of the valley of Big Sioux River in sec. 33, T. 89, N., R. 47 W. The section at the pit (fig. 14) operated in 1933 is given below:

Section: Sioux City Brick and Tile Co.,
Sioux City, Woodbury County, (1933)

Member	Description	Thickness Feet Inches
15	Loess.	20
14	Sand and gravel.	4

		Feet	Inches
13	Clay, buff, silty, weathered. (T)	6	
12	Shale, gray, silty, weathered.	3	
11	Shale, buff, silty, weathered, contains gypsum crusts and nodules.	6	
10	Shale, banded light and dark gray, silty.	2	6
9	Sandstone, soft, argillaceous, banded with limonitic streaks.	1	6
8	Sandstone, slabby, brown, calcareous.	5	
7	Shale, gray, light and dark banded, silty, much like member 10.	2	6
6	Clay, sandy, yellow, banded.	1	3
5	Clay, gray and black (carbonaceous), silty. (T)	4	
4	Clay, banded, dark gray, contains considerable number of interstratified carbonaceous layers.	18	
3	Lignite.		2
2	Sandstone, yellow.	3	
1	Clay, banded light and dark, contains numerous plant fragments and clay ironstone concretions. (T)	10	

Figure 14. Shale pit of the Sioux City Brick and Tile Company of Sioux City, Woodbury County.

All members of the above up to 14 were used except the hard and unweathered sandstone of 8 and 9. Quite definite stratification and much silty shale are notable features of the above section. The upper part of the section is notably weathered, and pyrite nodules and selenite crystals are abundant throughout.

Later a pit was opened 200 yards west of the above, believed to be somewhat lower than the previous section.

Section: Sioux City Brick and Tile Co.,
Sioux City, Woodbury County. (1935)

Member	Description	Thickness Feet	Inches
7	Loess.	15	
6	Shale, slabby, sandy, weathered, contains gypsum as a white powder and in veinlets.	5	6
5	Shale or clay, much like member 4 but contains more light colored streaks or bands.	10	
4	Shale, carbonaceous, with white silty bands or streaks, becoming less numerous toward top, where it is principally black argillaceous shale, contains gypsum in small crystals, zone about 6 feet from bottom is limonitic.	16	6
3	Sandstone, soft, yellow, strongly cemented with limonite at top.	3-4	
2	Shale, containing many sandy streaks, mostly finely banded, contains sandy layers up to 2 inches strongly cemented with limonite, clay ironstone concretions.	6	
1	Shale, gray, no banding, starchy fracture, resembles Sergeant Bluff material, contains carbonaceous material in lower 2 feet.	7	

Summarizing, the Cretaceous system of Woodbury County contains abundant shale suitable for heavy clay products, but these are not readily accessible except along the bluffs of Missouri and Big Sioux Rivers in the vicinity of Sioux City and Sergeant Bluff. Horizons particularly accessible in the vicinity of Sergeant Bluff are buff-burning and possibly somewhat refractory.

CERAMIC TESTS ON IOWA SHALES AND CLAYS

Many representative samples of shale and clay were collected in the course of the field study and 36, chosen for various reasons, were subjected to the tests recommended by the Standards Committee of the American Ceramic Society.[61] Some of those tested were selected because they were considered typical of the material of certain pits, others because they were considereed typical of much of the material used from a formation or series such as the Des Moines, and still others because they were stated to be markedly different in some property such as refractoriness. It is believed that the selection has been made so as to include a wide range of horizons and localities. These shales and clays were noticeably different in appearance in outcrop, or upon megascopic examination—in color, content of silt, sand or carbonaceous material, in apparent plasticity, and in other characteristics.

The results of the tests are presented in table 4, and a description and an explanation of each of the tests will be given in the following pages, so that their purpose may be understood.

[61]Beecher, M. F., Report for the year 1922, Committee on Standards, Am. Ceramic Soc. Year Book, 1921-1922, Jour., Am. Ceramic Soc., vol. 5, pp. 31-62, 1922.

TESTS ON UNBURNED CLAYS AND SHALES

Time of slaking is intended to show the readiness of the material to fall apart in water, a matter which is of importance in its use, since generally clays are pugged or mixed with water prior to molding. The clay is mixed with 50 percent of finely ground flint, pugged and made into cubes. After these have been dried to 110° C. they are cooled and submerged on a screen in water of 25° C. The time required for all of the material to crumble and pass through the screen is the time of slaking.

Volume shrinkage is the shrinkage of volume which the wetted and molded clay undergoes upon drying at 110° C. It has obvious value in that it discloses the extent to which clay ware will shrink in volume upon drying prior to burning. The volume shrinkage is arrived at by determining the difference between the volume of test bricks (1⅓ by 1⅛ by 1⅞ inches) when freshly made and again after drying. The volume is determined with a standard volumeter. It is expressed as a percent of the dry volume.

Linear shrinkage is the percent linear shrinkage as determined from the data secured in measuring the volume shrinkage and by the formula given below. A knowledge of the shrinkage is of importance to the user of clays inasmuch as it throws light upon the behavior to be expected of the clay ware in drying and in burning. A clay with a high linear and volume shrinkage might be expected to crack in burning; one with a low linear and volume shrinkage might yield a product open in texture and low in strength. The percent linear shrinkage is derived from the following formula:

$$a = \left[1 - \sqrt[3]{\frac{1-b}{100}} \right] \times 100$$

in which b = percent volume shrinkage and a = percent linear shrinkage.

Water of plasticity is the water present in a clay when it is in a sufficiently plastic condition so that it is suitable for molding into ware. It is stated in percent. A knowledge of the amount of the water of plasticity is useful in that it indicates the manner in which the clay will work, and the behavior to be expected of it in drying and burning. It is determined by mixing the clay to the proper consistency and making test pieces of a standard size (1⅛ by 1⅛ by 1⅞ inches). These are weighed in the moist condition, and again after drying to constant weight at 110° C. The difference between the two weights constitutes the water of plasticity and is expressed in percent of the dry weight.

Shrinkage water is that portion of the water of plasticity which is driven off up to the point where shrinkage ceases. The amount of this is related to the possible cracking to be expected of the ware in drying. It is determined from the formula:

$$t_1 = \frac{V_p - V_d}{W_d} \times 100$$

wherein t_1 = the percent shrinkage water.
V_p = the plastic volume in cubic centimeters.
V_d = the dry volume in cubic centimeters.
W_d = the dry weight in grams.

Pore water is that portion of the water of plasticity which is driven off from the point where shrinkage ceases until the clay piece has reached approximately constant weight at 110° C. A knowledge of this is useful in controlling the drying and burning of a clay. Since it is the difference between the water of plasticity and the shrinkage water, it is arrived at by subtracting the percent of shrinkage water from the percent of water of plasticity. It also is expressed in percent.

Transverse strength is the strength of the dried but unburned clay, expressed as the modulus of rupture in pounds per square inch. This is of obvious use to the clay products manufacturer inasmuch as it indicates the strength of the ware prior to burning and therefore the way in which it will stand up in the manufacturing process up to that point. For the purpose of this test, the clay is dried to 76° C., mixed with an equal amount of dry silica sand, and then made to a plastic consistency and pugged by hand. It is molded into test pieces 7 inches long and 1 inch in cross section. These are dried, first in the air and finally in the drying oven to 110° C., and then cooled in a dessicator. These test pieces are then broken in a suitable machine which determines the load at the time of rupture. The following formula is used:

$$M = \frac{3\ Pl}{2\ bd^2}$$

in which

M = the modulus of rupture in pounds per square inch.
P = the breaking load in pounds.
l = the distance between knife edges in inches.
b = the breadth of the bar in inches.
d = the depth of the bar in inches.

Ten bars are broken and the average modulus of rupture reported.

TESTS ON BURNED CLAYS AND SHALES

In order that the properties of the clay upon burning may be determined, test pieces (1⅛ by 1⅛ by 1⅞ inches) are prepared, dried, and the dry volume determined. They are then heated or burned in a refractory muffle, the temperature being controlled by means of Seger cones and by a thermocouple.

The use of these Seger pyrometric cones requires some explanation for those who are not familiar with clay ware manufacture. They are small cone-shaped test pieces used to determine the softening or fusing point of clay and clay ware. They are made of different mixtures of clay and fluxes, and the complete series of 64 cones represents a range in temperature from 590° C. for cone 022, to 2000° C. for cone 42. The numbers run from cone 022, through 021, 020, etc., to cone 1 and then from cone 1 up to cone 42. Each cone above cone 022 is approximately 20° C. higher than the one below it. In use, as the softening or fusing temperature of a cone is reached it gradually bends over until its tip touches the base on which it rests. The kiln is then stated to have reached the corresponding cone number. Similarly ware may be stated to have been burned to a certain cone number.

In this test work the temperature readings are reported in terms of cones. The heating is conducted at the rate of 45° C. per hour from the start of the firing until a heat treatment is reached, and 20° C. an hour from that point onward. A test piece is withdrawn at cone 010 and following that at intervals of two cones. The removal of the test piece is made quickly in each case, so that the furnace does not cool off appreciably. The test pieces as removed are covered with hot sand and when sufficiently cooled, are placed in a dessicator. They are then weighed (Wf) to 0.1 gram. Following this they are placed in distilled water, boiled for two hours, and cooled while still immersed in the water. The excess moisture is then removed and the piece weighed to 0.1 gram (Sf). The volume (Vf) of the respective test pieces is also determined by measurement in a volumeter, using distilled water as the liquid.

The apparent porosity is the porosity as shown by the amount of water taken up or retained when the specimen is boiled. It is expressed in percent and is determined with the use of the following formula:

$$P = \frac{Sf - Wf}{Vf} \times 100$$

where P = the percent apparent porosity.

Sf = weight of saturated fired test piece in grams.
Wf = weight of the fired test piece in grams.
Vf = volume of the fired test piece in cubic centimeters.

This is of importance in showing the amount of apparent pore space and the solidity of the fired or burned products. It also indicates the stage attained in the burning process.

The volume change is the volume change developed in the process of burning or firing and is represented by the difference in volume between the burned and unburned test piece. A knowledge of this volume change developed at a succession of temperatures obviously shows the extent to which fusion and vitrification have proceeded. The dry volume of the unburned test piece is determined by soaking it in kerosene until saturated and then determining the volume in a volumeter using kerosene as the fluid. The volume of the burned test piece is also determined, as explained previously. The volume change is expressed in percent, based on the dry volume of the unburned test piece.

Apparent specific gravity is the specific gravity or weight per unit per volume of the water-impermeable portion of the test piece. It is thus the specific gravity of the solid material plus the sealed pores or cavities. Used in connection with bulk specific gravity it throws light upon the degree of burning attained and on the amount of the closed cavities in the burned product. It is computed from the formula:

$$G = \frac{Wf}{Vf - (Sf\text{-}Wf)}$$

in which G = the apparent specific gravity.
Wf = the weight of the burned test piece.
Vf = the volume of the burned test piece.
Sf = the volume of the saturated burned test piece.

Bulk specific gravity is the specific gravity of the composite bulk; it may also be described as the specific gravity of the solid material plus the sealed pores or cavities plus the water-permeable pores. It is thus the weight per unit of exterior volume. As previously noted, this item is of value when used with the apparent specific gravity inasmuch as it gives an indication of the degree of burning attained and the nature of the openings in the burned product. It is computed from the formula:

$$G_b = \frac{Wf}{Vf}$$

in which G_b is the bulk specific gravity.

TABLE 4

Tests On Iowa Clays and Shales

Source of Clay	TESTS ON UNBURNED CLAY							TESTS ON BURNED CLAY							Remarks	SAG TEST	
	Time of Slaking Min.	Volume Shrinkage (b) Percent	Linear Shrinkage (a) Percent	Water of Plasticity (T) Percent	Shrinkage Water (t_1) Percent	Pore Water (t_2) Percent	Transverse Avg. (M) Lbs. sq. in.	Cone No.	Apparent Porosity (p) Percent	Volume Change (b_1) Percent	Apparent Sp. Gr. (G)	Bulk Sp. Gr. (G_b)	Absorption	Steel Hard At Cone No.		Cone No.	Sag Ratio (Avg.)
Adel Clay Products Co.	5.1	12.5	4.0	22.8	6.61	16.19	250.7	06	31.6	1.06	2.61	1.79	17.07				
Member 1								04	29.7	4.14	2.51	1.78	16.95				
								02	27.5	9.04	2.69	1.88	14.61	2	Burns light red. No tendency to warp or crack.		
								1	28.7	4.61	2.56	1.82	15.80				
								2	21.0	10.94	2.50	1.98	10.65				
								3	19.8	13.84	2.51	1.98	9.82				
								5	12.2	17.70	2.41	2.11	5.75				
Adel Clay Products Co.	12.1	30.4	9.3	23.9	15.6	8.3	210.6	06	27.2	7.6	2.64	1.92	14.1			5	.016
Member 2								04	22.3	2.8	2.49	1.95	11.1	02	Burns light red. Does not warp, crack, or swell.	01	.0057
								02	21.0	10.1	2.64	2.08	10.1				
								1	18.0	8.7	2.50	2.05	8.8				
								2	14.3	8.6	2.44	2.09	6.8				
								3	14.1	7.9	2.34	2.01	7.1				
								5	14.0	7.6	2.46	2.14	6.6				
Adel Clay Products Co.	7.45	18.3	5.7	32.3	10.5	2.18	218.7	06	29.1	9.8	2.60	1.85	15.8	02	Burns light red up to cone 2; vitrifies at higher temperature and takes on darker color. No tendency to crack or swell.	01	.0345
Member 4								04	24.5	14.3	2.29	1.91	12.9				
								02	11.8	26.4	3.52	2.16	5.3				
								1	17.4	15.5	2.49	1.95	9.2				
								2									
								3	6.6	32.5	4.59	2.44	2.7				
								5	0.83	27.1	3.67	2.29	3.6				
Adel Clay Products Co.	5.4	18.6	5.8	30.1	10.2	19.9	354.7	06	31.6	2.15	2.50	1.71	18.5	02	Burns light red. Vitrifies at cone 5.	01	.0134
Member 5								04	27.5	10.1	2.54	1.84	14.9				
								02	18.9	12.9	2.35	1.91	9.8				
								1	22.1	18.4	2.49	.....	11.4				
								2	No results (cracked)								
								3	11.3	21.3	2.36	2.09	5.4				
								5	1.15	23.5	2.26	2.23	0.52				
Centerville Clay Products Co.	6.1	15.3	4.9	27.5	8.5	19.0	164.5	06	34.7	13.5	2.96	1.94	17.9	02	Burns light red. Tendency to crack and swell above cone 1.	01	.0562
Member 2								04	25.9	12.7	2.50	1.83	14.6				
								02	9.7	25.0	2.44	2.18	4.4				
								1	3.7	17.3	2.17	2.09	1.8				
								2	Swelled and cracked								
								3	1.8	27.8	2.32	2.28	.79				
								5	Swelled								

Centerville Clay Products Co.	6.2	10.1	3.3	20.4	6.0	14.4	200.6	06	25.6	5.4	2.48	1.82	14.6	02	Burns light red. Vitrifies at cone 1 and takes on darker color. No tendency to crack or swell if properly fired.	5	.191
Member 3								04	12.2	10.8	2.34	2.05	5.9				
								02	7.6	25.6	2.39	2.21	3.5				
								1	6.6	11.7	2.22	2.08	3.2				
								2	Swelled								
								3	0.78	25.4	2.32	2.31	0.31				
								5	0.37	24.3	2.26	2.25	0.16				
Des Moines Clay Co.	6.75	26.4	8.1	31.1	14.5	16.6	297.5	06	20.4	10.6	2.39	1.90	10.7	06	Burns red. Marked tendency to crack and swell.	02	.0847
Member 18								04	13.4	22.6	2.53	2.19	6.1				
								02	4.1	25.1	2.34	2.25	1.8				
								1	Swelled and cracked								
								2	"	"	"						
								3	"	"	"						
								5	"	"	"						
Des Moines Clay Co.	10.1	26.2	8.1	24.7	13.1	11.6	360.8	06	22.6	3.54	2.59	2.00	11.3	02	Burns light buff. No tendency to crack or swell.	5	.0129
Member 15								04	22.6	1.67	2.54	1.97	11.5				
								02	18.2	7.03	2.49	2.02	9.3				
								1	21.5	6.41	2.64	2.07	10.4				
								2	14.2	7.31	2.42	2.07	6.9				
								3	14.3	11.4	2.45	2.10	6.8				
								5	Not burned								
Des Moines Clay Co.	11.8	21.2	6.6	23.9	11.1	12.8	361.9	06	25.8	8.4	2.59	1.92	13.4	02	Burns medium buff. Some tendency to crack.	5	.0143
Member 2 and 4								04	19.7	15.6	2.68	2.15	9.1				
								02	15.3	12.8	2.49	2.02	7.6				
								1	18.5	8.0	2.45	2.00	9.3				
								2	15.5	19.3	2.64	2.24	6.9				
								3	15.1	17.1	2.60	2.21	6.8				
								5	Not burned								
Des Moines Clay Co.	10.5	26.6	8.2	29.2	14.1	15.1	354.3	06	23.2	6.7	2.56	1.96	11.8	06	Burns red. Marked tendency to swell.	02	.0645
Plant Mix								04	Swelled badly								
								02	Swelled badly								
								1	13.9	11.7	2.31	1.99	7.0				
								2	Swelled badly								
								3	Swelled badly								
								5	Swelled badly								
Dewey Portland Cement Co.		31.2	9.5	32.4	17.2	15.2	304.8	06	26.6	12.4	2.59	1.90	14.0	04	Burns reddish buff. Marked tendency to crack and swell.	02	.0302
								04	16.9	15.7	2.39	1.99	8.5				
								02	Swelled								
								1	"								
								2	"								
								3	"								
								5	"								
Goodwin Brick and Tile Co.	17.0	25.3	7.8	26.4	12.8	13.6	351.2	06	26.0	2.5	2.60	1.92	13.5	2	Burns buff. No tendency to crack or swell.	02	.0044
Member 3								04	22.1	5.3	2.58	2.10	11.0				
								02	24.0	13.2	2.85	2.17	11.0			5	.0102
								1	24.0	11.2	2.74	2.08	11.5				
								2	20.6	11.1	2.57	2.16	8.1				
								3	20.8	6.3	2.53	1.92	10.9				
								5	20.2	8.7	2.51	1.97	10.3				
Kalo Brick and Tile Co.	Does	33.6	10.1	35.2	18.7	16.5	287.9	06	29.3	14.2	2.60	1.84	16.0	06	Burns buff. Iron spots badly. Tendency to warp and difficult to oxidize. Sag test failed to oxidize.	02	.0316
Member 1	not							04	23.7	24.0	2.64	2.01	11.8				
	slake							02	16.7	24.8	2.39	1.98	8.4				
	in							1	20.2	19.7	2.47	1.97	10.2				
	12							2	17.7	16.0	2.31	1.91	9.3				
	hours							3	16.5	18.6	2.32	1.93	8.6				
								5	14.6	14.5	2.08	1.77	8.2				

Tests On Iowa Clays and Shales—Continued

Source of Clay	TESTS ON UNBURNED CLAY							TESTS ON BURNED CLAY							Remarks	SAG TEST	
	Time of Slaking Min.	Volume Shrinkage (b) Percent	Linear Shrinkage (a) Percent	Water of Plasticity (T) Percent	Shrinkage Water (t_1) Percent	Pore Water (t_2) Percent	Transverse Avg. (M) Lbs. sq. in.	Cone No.	Apparent Porosity (p) Percent	Volume Change (b_1) Percent	Apparent Sp. Gr. (G)	Bulk Sp. Gr. (G_b)	Absorption	Steel Hard At Cone No.		Cone No.	Sag Ratio (Avg.)
Kalo Brick and Tile Co., Member 3	5.3	5.7	1.75	18.8	3.5	15.7	......	06	31.9	1.20	2.52	1.72	18.6	above	Very sandy open-burning clay. Burns reddish buff. Too "short" for casting into bars for sag test or strength test.	......	......
								04	34.1	.97	2.61	1.72	19.8	5			
								02	31.8	.48	2.58	1.76	18.1				
								1	33.6	.24	2.59	1.72	19.5				
								2	31.2	2.35	2.63	1.77	17.7				
								3	32.5	2.18	2.60	1.75	18.5				
								5	30.2	.47	2.53	1.76	17.2				
Mason City Brick and Tile Co., Member 1	9.0	18.5	5.8	29.5	10.4	19.1	232.0	06	27.0	6.5	2.43	1.77	15.3	04	Burns reddish buff. Marked tendency to swell above cone 02	02	.0417
								04	18.5	12.8	2.42	1.97	9.4				
								02	10.9	19.8	2.14	2.12	0.51				
								1	Swelled								
								2	"								
								3	"								
								5	"								
Mason City Brick and Tile Co., Member 2	13.3	21.1	6.6	24.7	11.5	13.2	255.7	06	46.8	2.66	2.92	1.56	30.1	above	Burns dark buff. Sandy open-burning clay.	5	0
								04	42.8	0.29	2.63	1.50	28.6	5			
								02	41.9	0.57	2.61	1.52	27.7				
								1	41.7	0.57	2.59	1.51	27.7				
								2	42.0	1.41	2.61	1.52	27.7				
								3	43.0	0.85	2.66	1.52	28.3				
								5	40.2	6.15	2.66	1.59	26.3				
Mason City Brick and Tile Co., Member 3	7.5	12.6	4.0	24.1	7.2	16.9	205.8	06	51.0	5.29	2.91	1.39	37.8	above	Burns dark buff. Sandy open-burning clay. Shows an increase in volume without warping or cracking.	......	......
								04	50.9	2.91	2.76	1.35	37.7	5			
								02	52.8	1.36	3.07	1.42	38.1				
								1	Cracked								
								2	50.0	1.05	2.87	1.45	34.5				
								3	50.5	1.05	2.51	1.32	35.1				
								5	49.2	1.63	3.10	1.43	34.4				
Ottumwa Brick and Tile Co., Member 4	9.6	15.1	4.8	24.0	8.2	15.8	289.9	06	26.2	0.27	2.38	1.76	14.9	04	Burns light buff. No tendency to deform.	5	.0362
								04	23.7	4.94	2.43	1.85	12.8				
								02	14.2	15.7	2.41	2.07	6.7				
								1	11.7	19.6	2.93	2.23	5.2				
								2	10.3	20.2	2.32	2.12	4.9				
								3	13.8	......	2.24	1.93	6.9				
								5	10.1	20.6	2.37	2.20	4.7				

Ottumwa Brick and Tile Co. Member 3	8.3	20.9	6.6	28.6	11.6	17.0	206.4	06	29.7	10.2	2.67	1.90	15.1	04	Burns light red. Marked tendency to crack and swell. Too "short" for sag test.		
								04	10.9	21.9	2.32	2.00	5.3				
								02	0.8	26.7	2.29	2.28	.35				
								1	Swelled badly								
								2	"	"							
								3	"	"							
								5	"	"							
Northwestern States Portland Cement Co. "Clay"	9.7	22.1	6.9	29.6	12.5	17.1	245.6	06	31.8	9.7	2.46	1.68	19.0	3	Burns medium reddish buff. Some tendency to swell.	5	.264
								04	31.7	5.8	2.44	1.67	19.0				
								02	26.8	6.2	2.36	1.73	15.5				
								1	27.4	8.1	2.36	1.73	16.0				
								2	Swelled								
								3	2.16	16.8	1.93	1.92	1.12				
								5	Swelled								
Red Oak Section Member 2	10.0	18.6	5.8	19.0	9.3	9.7	280.3	06	26.6	1.95	2.68	1.97	13.5	above 5	Burns light buff. No tendency to crack or swell.	5	.0029
								04	26.0	1.68	2.57	1.91	13.6				
								02	24.7	1.14	2.64	1.99	12.4				
								1	23.6	1.08	2.36	1.90	12.4				
								2	22.2	0.56	2.48	1.92	11.5				
								3	22.0	0.84	2.49	1.94	11.3				
								5	21.5	0.56	2.55	1.94	10.9				
Rockford Brick and Tile Co. Member 1	11.3	21.3	6.7	28.6	12.1	16.5	210.9	06	31.7	8.0	2.58	1.77	17.9	2	Burns light reddish buff. Some tendency to swell.	5	.202
								04	22.0	5.3	2.31	1.80	12.2				
								02	20.5	6.8	2.38	1.89	10.8				
								1	19.8	6.1	2.27	1.84	10.9				
								2	Swelled								
								3	"								
								5	"								
Sheffield Brick and Tile Co. Member 1	9.9	27.1	8.3	33.4	15.1	18.3	220.1	06	36.1	10.4	2.67	1.71	21.1	02	Burns light reddish buff up to cone 2. At higher cones the clay burns a brownish gray and shows tendency to swell.	5	.092
								04	32.7	11.2	2.49	1.68	19.5				
								02	27.5	12.7	2.34	1.70	16.2				
								1	24.5	6.3	2.31	1.75	14.0				
								2	20.4	14.6	2.20	1.82	11.0				
								3	17.9	11.2	2.22	1.82	9.9				
								5	10.0	14.3	1.93	1.88	0.53				
Sioux City Brick & Tile Co. (Riverside) Member 1	4.7	13.0	3.8	25.1	7.6	17.5	289.1	06	35.2	0.0	2.44	1.61	21.2	above 5	Burns medium buff. No tendency to crack or swell.	5	.0373
								04	35.0	0.78	2.48	1.63	21.6				
								02	31.5	2.79	2.46	1.68	18.7				
								1	31.3	2.68	2.48	1.70	18.4				
								2	29.2	4.37	2.39	1.72	16.9				
								3	29.7	5.03	2.41	1.72	17.2				
								5	25.2	6.43	2.43	1.82	13.9				
Sioux City Brick and Tile Co. Member 5	20.3	25.6	7.9	35.1	15.1	20.0	209.9	06	33.4	4.97	2.49	1.68	19.4	04	Burns medium buff. No tendency to crack or swell.	01	.0057
								04	22.8	16.1	2.40	1.85	12.3				
								02	19.2	16.1	2.37	1.92	10.0				
								1	16.4	19.7	2.32	1.94	8.4				
								2	13.2	24.1	2.38	2.07	6.4				
								3	10.2	21.8	2.20	1.98	5.2				
								5	4.6	21.8	2.25	2.04	4.6				

Tests On Iowa Clays and Shales—Continued

Source of Clay	TESTS ON UNBURNED CLAY: Time of Slaking Min.	Volume Shrinkage (b) Percent	Linear Shrinkage (a) Percent	Water of Plasticity (T) Percent	Shrinkage Water (t_1) Percent	Pore Water (t_2) Percent	Transverse Avg. (M) Lbs. sq. in.	TESTS ON BURNED CLAY: Cone No.	Apparent Porosity (p) Percent	Volume Change (b_1) Percent	Apparent Sp. Gr. (G)	Bulk Sp. Gr. (G_b)	Absorption	Steel Hard At Cone No.	Remarks	SAG TEST: Cone No.	Sag Ratio (Avg.)
Sioux City Brick and Tile Co. (Riverside) Member 13	13.0	24.7	7.3	34.3	14.6	19.7	220.8	06	22.9	17.6	2.53	2.02	11.8	06	Burns red. Cracks and swells badly.	02	.0230
								04	Swelled badly								
								02	"	"							
								1	19.1	21.2	2.49	2.02	9.5				
								2	Swelled badly								
								3	"	"							
								5	"	"							
Sioux City Brick and Tile Co. (Sergeant Bluff) Member 1	12.0	26.1	8.0	24.1	13.1	11.0	339.2	06	24.3	3.5	2.60	1.98	12.1	06		02	.0079
								04	22.7	3.9	2.52	1.96	11.5		Burns medium buff. Some tendency to crack and swell at the higher temperatures.	5	.0179
								02	Cracked								
								1	18.5	4.7	2.42	1.97	9.4				
								2	4.5	7.7	2.32	2.21	2.05				
								3	4.2	10.1	2.17	2.08	1.96				
								5	4.5	10.7	2.16	2.07	1.98				
Sioux City Brick and Tile Co. (Sergeant Bluff) Member 2, Lower 10 ft.	10.3	22.0	6.9	21.6	10.7	10.9	308.3	06	23.2	1.36	2.38	1.83	12.7	02		5	.0118
								04	23.8	1.97	2.60	1.98	12.1		Burns medium buff. Does not crack or swell. Some very small iron spots.		
								02	14.6	10.4	2.43	2.05	7.15				
								1	16.4	12.3	2.64	2.29	7.16				
								2	10.0	6.4	2.24	2.01	4.97				
								3	10.0	6.1	2.31	2.08	4.79				
								5	Not burned								
Oskaloosa Clay Products Co. (Oskaloosa pit) Member 1	4.6	15.9	5.1	24.7	8.6	16.1	72.0	06	37.6	1.54	2.73	1.63	23.0	about 3			
								04	35.6	5.25	2.64	1.70	20.9		Burns red. Sandy open-burning clay. Too fragile to set for sag test.		
								02	24.6	16.2	2.48	1.85	13.3				
								1	23.5	18.4	2.54	1.94	12.1				
								2	20.9	19.6	2.52	1.99	10.5				
								3	Swelled				8.0				
								5	16.9	23.0	2.53	2.11					
Oskaloosa Clay Products Co. (Oskaloosa pit) Member 2	7.5	11.5	3.7	19.6	6.1	13.5	158.9	06	Not burned hard enough					about 5		5	.089
								04	Not burned hard enough						Burns dark buff. Slakes down in water when fired at the lower temperatures because of high lime content. Sandy, open-burning.		
								02	Slaked down in water								
								1	49.2	1.08	3.07	1.56	31.5				
								2	46.2	.77	2.77	1.49	31.1				
								3	45.1	2.06	2.72	1.49	30.3				
								5	40.1	5.35	2.64	1.58	25.4				
Oskaloosa Clay Products Co. (Oskaloosa pit) Member 3	8.2	28.1	8.6	33.2	16.6	16.6	302.8	06	34.1	0.30	2.41	1.59	21.5	02		01	0
								04	24.7	0.30	2.06	1.56	15.8		Burns medium to light buff. Not much tendency to swell.		

								02	21.3	13.50	2.26	1.76	12.5				
								1	24.6	13.70	2.41	1.78	12.8				
								2	16.4	21.20	2.35	1.96	8.4				
								3	13.8	22.90	2.30	1.98	7.0				
								5	3.8	22.40	2.15	2.06	1.8				
Vincent Clay Products Co.	10.3	24.9	7.7	29.4	13.5	15.9	265.6	06	20.3	13.8	2.48	1.98	10.3	06	Burns light red. Swells badly.	02	.0129
Member 2								04	Swelled								
								02	,,								
								1	11.7	21.9	2.38	2.10	5.6				
								2	Swelled								
								3	,,								
								5	,,								
Vincent Clay Products Co.	7.3	11.4	3.7	17.6	5.8	11.8	295.5	06	28.0	0.78	2.62	1.89	14.9	above 5	Burns a very light pinkish red. Shows no tendency to swell.	5	0
Member 3								04	25.9	0.26	2.61	1.92	13.8				
								02	26.4	1.33	2.66	1.93	14.0				
								1	27.6	0.77	2.52	1.85	14.3				
								2	25.6	1.30	2.52	1.94	13.2				
								3	26.4	2.36	2.75	2.00	13.7				
								5	25.9	3.36	2.64	1.96	13.3				
Vincent Clay Products Co.	11.8	19.7	6.1	24.5	10.3	14.2	330.6	06	26.0	2.9	2.51	1.86	14.0	02	Burns light red. Little tendency to swell.	02	.0086
Member 4								04	21.6	13.2	2.62	2.04	10.6				
								02	11.4	13.9	2.40	2.13	5.4				
								1	9.1	10.7	2.41	2.13	4.1				
								2	6.3	14.9	2.21	2.07	3.0				
								3	5.5	14.8	2.29	2.18	2.5				
								5	3.7	16.9	2.22	2.14	1.7				
What Cheer Clay Products Co.	8.8	15.7	5.0	23.9	8.5	23.4	258.8	06	29.3	1.6	2.55	1.81	16.2	2	Burns medium buff. No tendency to swell or crack.	5	.0354
Member 1								04	28.9	1.8	2.49	1.77	16.0				
								02	22.7	6.9	2.42	1.84	12.1				
								1	22.8	9.4	2.51	1.91	11.7				
								2	18.2	12.4	2.45	2.01	9.1				
								3	17.5	13.0	2.56	2.11	8.3				
								5	No results, not burned								
What Cheer Clay Products Co.	9.8	30.8	9.4	37.0	18.0	19.0	259.7	06	43.7	22.6	3.59	2.02	20.6	06	Burns light red below cone 1 and a dark red brown above cone 1. Tends to swell and crack. No sag test run.		
Member 4								04	28.4	21.3	3.26	1.94	14.6				
								02	23.1	16.3	2.39	1.80	12.8				
								1	19.9	22.5	2.48	1.99	10.1				
								2	14.6	15.2	2.13	1.82	8.0				
								3	11.1	21.7	2.14	1.90	5.8				
								5	10.2	10.5	1.98	1.78	5.7				

*These tests were made upon samples collected by the writer. Tests were made by Mr. A. L. Bock in the laboratories of the Department of Ceramic Engineering of Iowa State College, under the supervision of Prof. Paul E. Cox. The shales and clays included in this table are marked (T) where referred to elsewhere in the report.

Absorption is reported as a percentage of the weight of the dry sample and represents the water absorbed by the test piece. It measures the degree to which burning has proceeded. It is obtaind by dividing the weight in grams of water absorbed by the weight in grams of the dry test piece.

Hardness. The point at which steel hardness is attained is reported under this heading. It is determined by testing the burned specimen with a piece of steel. It measures the extent or degree to which vitrification has been reached.

Color changes and behavior in burning. Under the heading of "Remarks" any other changes noted in the course of the burning are recorded. These may include color changes and such things as warping and cracking. Many of the clays and shales showed a tendency to swell or crack in these small-scale tests. Most of these would probably be found to fire without trouble under the more prolonged firing conditions used in commercial kilns. The behavior in these tests shows however that the possibility of trouble in this regard does exist.

Sag or warpage ratio is the ratio of the amount of deflection developed in burning to the length of a test bar. It is devised to determine the temperature of and rate of softening upon heat treatment. In this determination bars of the clay are cast ½ by 1 by 9 inches. These are dried and are placed in the kiln with the 1-inch dimension resting upon knife edges 7 inches apart. Firing is conducted at a specific rate. The amount of deflection is measured in tenths of a millimeter, and the ratio of this to the span of 7 inches is computed.

Summary of tests. Standard tests have been conducted on these shales and clays, and results show them to range considerably in the various properties, but hardly more than would be expected of a range of shales and clays used in heavy clay products manufacture.

These tests, conducted upon both unburned and burned ware, are recognized by ceramists as giving as good an idea at least of the manufacturing properties of a shale or clay as can be secured in such small-scale tests, although the extent to which they indicate behavior in manufacturing practice is not agreed upon. The tests and their significance are well understood by manufacturers of ceramic ware and by ceramic engineers.

CHEMICAL ANALYSES OF IOWA SHALES AND CLAYS

No chemical analyses have been made in the course of this study, but partial analyses made in the laboratories of the Pennsylvania-Dixie Cement Co. of West Des Moines and the Northwestern States Portland Cement Co. of Mason City, and kindly furnished by the management of those companies, are listed in table 5. Sodium, potassium, water and carbon dioxide have not been determined, but the analyses are useful in that they disclose the percent of the other constituents.

Nos. 1 to 28 inclusive (table 5) are presumably from the Des Moines series and are considered representative of the materials used in the ceramic industry. Nos. 29 to 37 inclusive are from the Missouri series. They are not used in the ceramic industry, being generally unsuitable because of the high lime content. Nos. 1 to 37 inclusive are from the Pennsylvania-Dixie Cement Co., and 38 to 45 from the Northwestern States Portland Cement Co. The latter are from the Devonian beds in the vicinity of Mason City.

Chemical analyses of shales and clays are of limited use to a clay products manufacturer, since only the general physical properties can be deduced therefrom. A high silica content indicates the presence of silica in the form of silt or sand, and such material may be found to be lacking in plasticity and to burn at a high temperature. Iron, calcium, magnesium, sodium and potassium act as fluxes and tend to lower the burning temperature, particularly true of sodium and iron. Iron gives a red color to the product and calcium a buff color. High calcium and magnesium also generally mean a high carbon dioxide content, with resultant swelling upon burning, and the possible development of free lime.

TABLE 5

Analyses of Iowa Shales and Clays

No. Source and Description of Clay or Shale	Percent				
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Standard Clay Products Co., Harvey, Marion County.					
1. Black shale, old pit.	72.4	13.8	3.6	0.3	0.6
2. Clay with the appearance of fire clay.	77.2	14.6	1.9	0.4	0.6
3. Plastic clay underlying No. 2	65.9	18.9	3.4	0.3	0.8
Wabash Railroad cut near Harvey, Marion County.					
4. Black shale.	48.5	16.1	18.6	0.3	0.8
United Brick and Tile Co., Carlisle, Warren County.					
5. Yellow shale, 16 feet, (Top).	68.6	14.4	5.6	1.4	1.2
6. Pale blue-gray shale, 5 feet (Middle)	61.2	20.1	6.9	1.2	1.2
7. Blue-gray shale, 2 feet (Bottom)	55.0	23.4	5.6	1.0	1.0

Goodwin Brick and Tile Co., southeast Des Moines, Polk County.					
8. Yellow sandy clay.	74.1	12.1	4.7	2.0	1.3
9. Red sandy clay east of No. 8 (Top)	76.2	10.8	5.7	1.4	1.0
10. Gray clay (10 feet) and blue shale (10 feet).	55.4	18.4	11.7	2.2	1.7
11. "Cap" rock, 8 inches.	11.3	7.0	10.9	26.2	10.0
12. Hard gray shale, 5 feet	60.00	18.3	8.0	1.5	2.0
13. Black shale, 5 feet.	61.2	23.4	1.3	1.5	1.0
14. Hard gray shale, 8 feet. (Bottom)	68.9	11.5	9.3	1.4	1.0
Iowa Pipe and Tile Co., Des Moines, Polk County.					
15. Shale, 6 feet, under upper "cap" rock.	65.2	19.2	7.2	0.3	1.0
16. Shale, 6 feet, under second "cap" rock	52.6	24.1	9.3	0.6	2.0
Exposures on the Valley Drive on property of Des Moines Water Works, Polk County.					
17. Top 10 feet.	59.5	21.4	6.4	1.7	1.4
18. Blue shale, bottom of exposure, 10 feet	50.9	24.5	5.5	0.4	1.4
Road cut, 2½ miles west of West Des Moines, Polk County.					
19. Yellow clay or shale, 13 feet (Top).	66.3	11.5	4.1	4.3	2.8
20. Blue-gray shale, 7 feet.	67.2	12.8	4.0	3.9	1.9
21. Blue-gray shale, 7 feet (Bottom)	69.5	12.2	3.1	3.2	2.3
Des Moines Clay Co., Des Moines, Polk County.					
22. Hard blue-gray shale, below overburden.	69.1	12.4	3.6	2.7	0.3
23. Brittle blue-gray shale, above "cap" rock.	68.4	16.1	4.8	1.0	0.7
Pit at Van Meter, Dallas County.					
24. Red shale below 'cap" rock.	59.5	18.7	9.4	1.3	1.2
Vincent Clay Products Co., south of Fort Dodge, Webster County.					
25. Red granular clay.	58.8	21.0	7.8	0.4	0.5
U. S. Gypsum Co., Fort Dodge, Webster County.					
26. Blue-gray and red shale, 6 feet (Top).	62.3	22.4	3.6	0.5	0.9
27. Dark gray-blue and red shale, 6 feet	53.1	21.6	9.6	1.2	1.5
28. Light gray-blue and red shale, 6 feet (Top).	66.3	17.7	5.5	0.3	0.5
Quarry, 3½ miles north of Winterset, east of Highway 16, Madison County.					
29. Black shale, 2 feet (Top).	51.6	17.1	6.2	3.0	2.1
30. Gray-blue shale, 9 feet	64.7	15.8	4.1	2.6	1.8
31. Limy shale, 10 inches	34.6	7.1	1.9	28.4	1.8
32. Limy shale, 14 inches. (Bottom)	23.8	5.5	2.4	33.0	3.5
Quarry ½ mile west of Earlham, Madison County.					
33. Six feet of shale at top of quarry.	57.5	13.7	4.2	7.5	1.9
Winterset, Madison County.					
34. Sample of 28 cars blue and black shale beneath 18 feet of limestone.	50.1	12.8	5.3	10.1	3.1
Quarry of Hawkeye Portland Cement Co., Earlham, Madison County.					
35. Upper ledge of shale; blue shale.	60.3	13.2	5.2	4.5	3.0
36. Black shale.	40.1	10.9	5.5	3.6	5.5
37. Yellow, limy shale.	26.8	8.9	3.7	25.7	3.1
Northwestern States Portland Cement Co. shale pit, Mason City Cerro Gordo County.					
38. "Blue" clay; used in the ceramic industry at Mason City.	49.00	19.73	2.95	7.72	3.87
39. Same	48.16	19.41	3.99	5.88	4.06
40. Same	50.20	18.78	4.62	1.32	4.15
41. Same	53.88	20.74	3.70	2.64	3.80
42. Same	53.20	20.84	3.04	2.96	3.54
43. Same	54.28	20.75	4.65	2.64	3.57
44. Same	54.56	20.43	3.61	2.80	3.60
45. Same	56.20	21.11	3.89	2.44	2.79

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CAMBRIAN STRATA OF NORTHEASTERN IOWA

by

WALTER C. SCHULDT

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CAMBRIAN STRATA OF NORTHEASTERN IOWA

BY WALTER C. SCHULDT

Abstract

The area of Cambrian sediments of northeastern Iowa has been studied with the dual aim of interpreting these rocks in the light of present knowledge of the stratigraphy of the Cambrian and of determining the nature and extent of lithologic variation over a small area.

Two cross sections are presented to show lateral and vertical variation of grain size and percentage of carbonate throughout the area. A structure-contour map, drawn on the Cambro-Ordovician boundary, shows several well-defined northwest-southeast trending structural highs within the area.

The Cambrian strata in northeastern Iowa are found to conform to the classification adopted by the ninth annual field conference of the Kansas Geological Society in 1935, and are subdivided into the Dresbach, Franconia, and Trempealeau formations in ascending order.

Detailed studies of the Madison member of the Trempealeau formation show that general characteristics such as fineness of grain, thin bedding, flat-pebble conglomerates, and green shale partings occur over the entire eastern half of the area, but that individual beds vary gretaly in lithology over a very short distance, and that it is nearly impossible to identify an individual bed from exposure to exposure. In the western half of the area, the member undergoes a complete change in character, becoming coarser grained and more massively bedded, so that differentiation from the remainder of the Jordan member is very difficult.

No evidence is found to indicate the presence of any pronounced breaks in the Cambrian sequence.

INTRODUCTION

The Problem

Since the work of Calvin,[1] there has been no systematic investigation of the Cambrian strata exposed in Iowa, and the only published work of any nature regarding the exposed Cambrian in the state has been that in connection with the production of a new geologic map for Iowa by Tester[2] in 1937. In the adjacent states of Wisconsin and Minnesota, considerable recent work has done much to advance ideas regarding Cambrian stratigraphy, and correlation has undergone considerable evolution. It seems advisable, therefore, that these sediments in Iowa be studied in the light of present correlations and knowledge, in particular since the out-

[1]Calvin, Samuel, Geology of Allamakee County: Iowa Geol. Survey, vol. 4, pp. 54-61, 1895.
[2]Tester, A. C., Geologic map of Iowa, Iowa Geol. Survey, 1937.

crop area in Iowa lies adjacent to a large area of Cambrian sediments covered by younger rocks and inaccessible to study except through the medium of subsurface data.

Because of the abundance and excellence of exposures and the limited area of outcrop, a detailed study has been made of Oneota-Madison-Jordan relationships with the aim of determining the degree of lithologic variation over a small area, and the discovery of any "marker" beds which might be of value in subsurface correlation.

The Investigation

Fourteen weeks, during the field seasons of 1938 and 1939, were spent in an intensive study of the outcrop area represented in plate 1. One hundred forty-seven sections were described in detail and an altimeter elevation was obtained for each.

During the fall and winter of 1939, mechanical analyses and insoluble residue determinations were made on 500 channel samples collected during the previous summers.

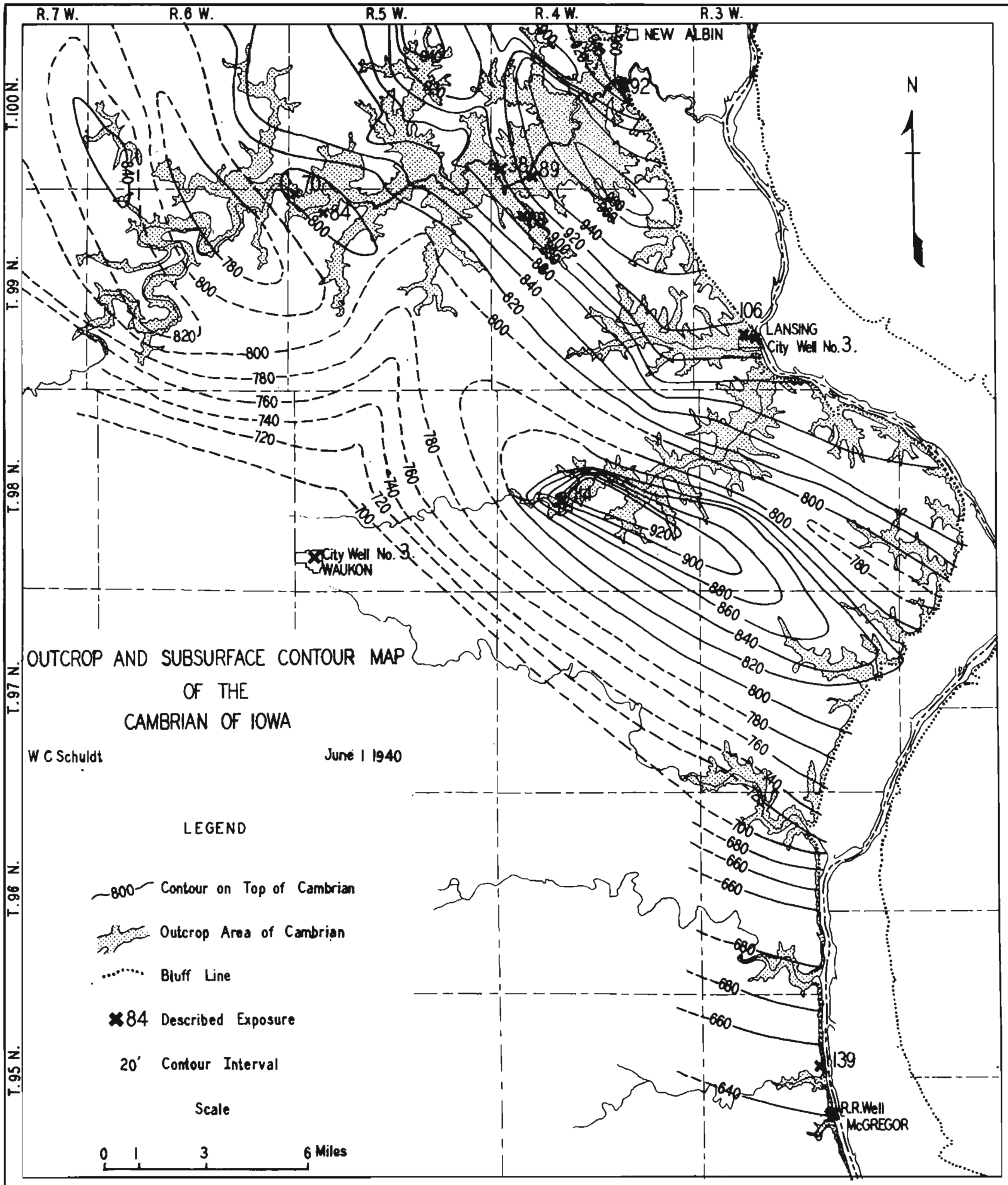
Many of the described sections are included in the accompanying appendix, and results from the laboratory work have been plotted on two large cross sections to show lateral changes in grain size and sorting.

Acknowledgements

The writer wishes to express his gratitude to Dr. A. C. Trowbridge, who directed field and laboratory work and under whose general supervision this report was written, and to acknowledge the aid extended by Mr. Gilbert O. Raasch, who very kindly examined and identified all the fossils collected. Gratitude is also extended to Professor Shorey of the mining department of the University of Wisconsin, who kindly permitted the writer to use the equipment and laboratories of the mining school to crush the samples. Mr. Herbert Yoho, graduate student, was employed during preparation of insoluble residues.

GENERAL STATEMENT

The Cambrian strata of the Upper Mississippi Valley, and of Iowa in particular, consist almost entirely of sandstones and siltstones with one thin band of dolomite and considerable dolomite


R.7 W.
R.6 W.
R.5 W.
R.4 W.
R.3 W.
T.100 N.
T.99 N.
T.98 N.
T.97 N.
T.96 N.
T.95 N.
NEW ALBIN
LANSING
City Well No. 3.
City Well No. 3.
WAUKON
R.R.Well
McGREGOR
N
OUTCROP AND SUBSURFACE CONTOUR MAP
OF THE
CAMBRIAN OF IOWA
W C Schuldt
June 1 1940
LEGEND
800 Contour on Top of Cambrian
Outcrop Area of Cambrian
Bluff Line
84 Described Exposure
20' Contour Interval
Scale
0 1 3 6 Miles

cementation near the top. The sandstones belong wholly to the Upper Cambrian or St. Croixan series, and are divided into the Dresbach, Franconia, and Trempealeau formations in ascending order. Table 1, a generalized section for the Cambrian of northeastern Iowa, shows the present classification, including members, with a general description of the lithology and approximate thicknesses.

Fossils are rare and fragmentary throughout most of the section, and correlations have been made primarily on the basis of lithologic evidence. Almost all contacts are transitional and no evidence was found for any major break. Despite this fact, however, in the majority of cases, contacts can be placed with considerable assurance on the basis of lithology.

Because the Dresbach formation is questionably represented by one small exposure showing only the topmost beds, lithologic descriptions for the members of the Dresbach formation have of necessity been taken from a study of the subsurface geology as interpreted from well cuttings.

The Franconia in this area is poorly exposed and very difficult to correlate owing to the sparsity of fossils and small exposures. For this reason, thicknesses and descriptions for members of the Franconia have been taken from published descriptions of Wisconsin sections.

TABLE 1

General Section of the Cambrian of Northeastern Iowa

	Feet
St. Croixan series	
Trempealeau formation	
Madison member	
Fine-grained, thin-bedded, cross-laminated, dolomitic sandstone, conglomeratic and green shaly in parts	3 - 22
Jordan member	
Van Oser facies	
Brown, coarse-grained, well-sorted, unconsolidated, massive sandstone with numerous sand-calcite nodules and dolomitic ledges in upper part, grading down into:	20 - 50
Norwalk facies	
Fine-grained, well-sorted, massive sandstone, unconsolidated in upper part, becoming strongly cemented and blocky at base	50 - 80
Lodi member	
Buff, thin-bedded, siltstones to fine-grained sandstones, fossiliferous in some beds	17 - 35
St. Lawrence member	
Pink, sandy, glauconitic dolomite in upper part and thin-bedded, glauconitic siltstones below	10 - 20
Franconia formation	
Bad Axe member	
Friable, green-gray, fine-grained sandstone to siltstone, sparsely fossilifeous	30
Hudson member	
Buff to green, laterally variable, thick-bedded, fine-grained, flour-like sandstone beds differentiated principally on basis of faunal criteria	80
Goodenough member	
Cross-laminated greensands with irregular, buff mottled appearance at top, underlain by thin-bedded, fine-grained, micaceous sandstone, in turn underlain by fine-grained, calcareous, glauconitic sandstone at base	30
Ironton member	
Buff to brown, massive, coarse-grained, well to poorly sorted, fossiliferous sandstone	18
Dresbach formation	
Galesville member	
White, clean, fine- to medium-grained, well-sorted, unconsolidated, nonfossiliferous sandstone	75 - 90
Eau Claire member	
Buff, fine-grained, slightly glauconitic, fossiliferous sandstones to siltstones	135
Mt. Simon member	
White to buff, medium- to coarse-grained, unconsolidated, nonfossiliferous sandstones	330

HISTORY OF NOMENCLATURE

Several recent summaries of the development of stratigraphic knowledge and correlation of the Cambrian strata in the Upper Mississippi Valley make a detailed review of the history of Cambrian nomenclature unnecessary. It is therefore intended to present only an outline of this phase of the subject, drawing freely upon the historical portions of other papers published recently and extending beyond them to include more recent work.

The Cambrian sediments of the Upper Mississippi Valley were studied by Owen as early as 1848 in a geological survey of Wisconsin, Iowa and Minnesota. In Owen's final report[3] of 1852, the Cambrian strata were designated as Formation 1 and were correlated with the Potsdam of New York State. No names were proposed, but six divisions or units were recognized and designated alphabetically. Winchell[4] in 1874, working on the Minnesota section, proposed the name St. Lawrence for limestone beds being quarried for building stone near that village (now non-existent). He also used the term Jordan, but both Jordan and St. Lawrence as of Ordovician age, confusing them with the New Richmond-Oneota sequence and placing the top of his St. Croixan series at the base of the St. Lawrence.

Irving[5] in 1875, working in the Cambrian of Wisconsin, applied the names Madison, Mendota, and Potsdam to the strata included in Owen's Formation 1. The Madison applied to what is now the Madison-Jordan sequence, the Mendota was equivalent to the Lodi and St. Lawrence of today, and the Potsdam included all of the Cambrian below the base of the St. Lawrence. In 1882, Wooster[6] applied the term Eau Claire Trilobite Bed to the middle shaly portion of the sandstone now comprising the Dresbach formation, and used the term Eau Claire Grits for the clean coarse rounded and frosted sandstone underlying the Eau Claire beds. He likewise proposed the term Hudson Trilobite Bed for the beds now known as the Hudson member of the Franconia. In 1886, Winchell[7] correlated the St. Lawrence of Minnesota with Irving's Madison of Wis-

[3]Owen, D. D., Report of a geological survey of Wisconsin, Iowa and Minnesota and incidentally a portion of Nebraska Territory, Lippincott, Grambo and Co., Philadelphia, pp. 52-58, 1852.

[4]Winchell, N. H., The geology of the Minnesota Valley: Minnesota Geol. and Nat. History Survey 2d Ann. Rept., pp. 147-156, 1874.

[5]Irving, R. D., Note on some new points in the elementary stratification of the primordial and Canadian rocks of south central Wisconsin: Am. Jour. Sci., 3d ser., vol. 9, pp. 441-442, 1875.

[6]Wooster, L. C., Geology of the lower Saint Croix district: Geology of Wisconsin, vol. 4, pp. 112-116, 1882.

[7]Winchell, N. H., Revision of the stratigraphy of the Cambrian in Minnesota: Minnesota Geol. and Nat. History Survey 14th Ann. Rept., pp. 325-337, 1886.

consin, placing both formations within the St. Croixan. He repeated this correlation in 1888 using the term Dresbach for the beds now comprising the Galesville and Eau Claire members and designating the underlying sandstone as Hinckley.

Hall[8] in 1911 and Norton[9] in 1912, working under the auspices of the U. S. Geological Survey, expanded the St. Lawrence downward to include most of the beds now known as Franconia.

In 1897, C. P. Berkey[10] named the Franconia sandstone from exposures in the vicinity of Franconia, Minnesota. Until 1911, the Madison-Mendota sequence of Irving had been in common use in Wisconsin, where it was considered by Winchell[11] as equivalent to the Jordan-St. Lawrence sequence of Minnesota. In 1911, Ulrich[12] questioned the position of the Mendota and in 1914 he[13] placed both Madison and Mendota above the Jordan, introducing the terms Jordan and St. Lawrence into Wisconsin. For the next 20 years there was much controversy concerning the position and existence of the Mendota. It has finally been generally accepted by Trowbridge, Atwater,[14] and others[15] and by Twenhofel, Raasch and Thwaites[16] that the Mendota of Ulrich is non-existent and that the beds called Mendota by him are actually the equivalent of the St. Lawrence of Minnesota. The controversy, however, has caused the redefinition and decline in importance of the term Madison, which originally including all Cambrian beds above the St. Lawrence, was first restricted to the fine-grained, thin-bedded, dolomitic transition beds at the top of the Jordan, and finally in later publications was relegated to member status. In Walcott's publication of 1914, Ulrich[17] applied the term Franconia to the Wisconsin section, restricting the St. Lawrence to its original limits. He also restricted the Dresbach to the beds below the Franconia and above the Eau Claire beds of Wooster,[18] and applied the

[8]Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, p. 36, 1911.
[9]Norton, W. H., and others, Underground water resources of Iowa: U. S. Geol. Survey Water-Supply Paper 293, p. 60, 1912.
[10]Berkey, C. P., Geology of the Saint Croix Dalles: Am. Geologist, vol. 20, pp. 373, 377, 1897.
[11]Winchell, N. H., Revision of the stratigraphy of the Cambrian in Minnesota: Minnesota Geol. and Nat. History Survey 14th Ann. Rept., pp. 325-337, 1886.
[12]Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pl. 27, 1911.
[13]Ulrich, E. O., in Walcott, C. D., Cambrian geology and paleonthology: Smithsonian Misc. Coll., vol. 57, p. 354, 1914.
[14]Trowbridge, A. C., and Atwater, G. I., Stratigraphic problems in the upper Mississippi Valley: Geol. Soc. America Bull., vol. 45, p. 79, 1934.
[15]Trowbridge, A. C., and others, Kansas Geol. Soc. Guidebook, 9th Ann. Field Conf., p. 18, 1935.
[16]Twenhofel, W. H., Raasch, G. O., and Thwaites, F. T., Cambrian strata of Wisconsin: Geol. Soc. America Bull., vol. 46, p. 1690, 1935.
[17]Ulrich, E. O., in Walcott, C. D., *op. cit.*
[18]Wooster, L. C., Geology of the lower Saint Croix district: Geology of Wisconsin, vol. 4, pp. 112-116, 1882.

term Mt. Simon to the clean, coarse, unfossiliferous sandstones underlying the Eau Claire beds.

Ulrich[19] in 1920, used the term Mazomanie formation for glauconitic beds which, he asserted, overlapped the Franconia in northeastern Wisconsin, and were therefore younger in their entirety than the glauconitic beds of western Wisconsin. The term was used by Thwaites[20] but the latter disclaimed responsibility for the belief that the Mazomanie is younger than the Franconia, and in 1931 Pentland[21] showed by heavy mineral studies that the Mazomanie of eastern Wisconsin is a close equivalent to the Franconia of western Wisconsin.

In 1924, Ulrich[22] proposed the term Trempealeau to replace the variously interpreted St. Lawrence and extended it upward to include the lower fine-grained Norwalk phase of the Jordan. Stauffer[23] objected to the inclusion of the Norwalk in the newly proposed Trempealeau, since at Jordan, the type section for the Jordan formation, only the finer grained Norwalk phase is present. He therefore continued to use the Minnesota term St. Lawrence, excluding from it a part of the Franconia. He included the remainder of the Franconia and part of the present Galesville in his Franconia, and included the remainder of the Galesville and the Eau Claire in his Dresbach formation. He also included the Hinckley sandstone as equivalent to the Mt. Simon of the Wisconsin section. Ulrich and Resser,[24] in 1930 followed Ulrich's classification of 1924 with the exception that the Eau Claire is expanded to include the present Mt. Simon. In publishing a geological map of Minnesota by Grout and others,[25] the Minnesota Geological Survey in 1932 followed Stauffer's classification of 1927.

In 1934, Trowbridge and Atwater,[26] reviewing the stratigraphic problems of the Upper Mississippi Valley, suggested that the three divisions of the strata underlying the Franconia, while

[19]Ulrich, E. O., Major causes of land and sea oscillations: Washington Acad. Sci. Jour., vol. 10, pp. 74-76, 1920.

[20]Thwaites, F. T., Paleozoic rocks found in deep wells in Wisconsin and northern Illinois: Jour. Geology, vol. 31, pp. 529-555, 1923.

[21]Pentland, A., Heavy minerals of the Franconia and Mazomanie sandstones, Wisconsin: Jour. Sedimentary Petrology, vol. 1, pp. 23-36, 1931.

[22]Ulrich, E. O., Notes on new names in the table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin: Wisconsin Acad. Sci. Arts and Letters Trans., vol. 21, p. 83, 1924.

[23]Stauffer, C. R., Age of the Red Clastic series of Minnesota: Geol. Soc. America Bull., vol. 38, pp. 472-474, 1927.

[24]Ulrich, E. O., and Resser, C. E., Cambrian of the upper Mississippi Valley: Milwaukee Public Mus. Bull., vol. 12, no. 1, p. 11, 1930.

[25]Grout, F. F., and others, Geologic map of Minnesota, Minnesota Geol. Survey, 1932.

[26]Trowbridge, A. C., and Atwater, G. I., Stratigraphic problems in the upper Mississippi Valley: Geol. Soc. America Bull., vol. 45, p. 79, 1934.

generally recognizable, were at the same time transitional from one to the other and were consequently more nearly of member than of formational rank. They therefore proposed to use the term Dresbach in a formational sense to include all three horizons, and suggested the new name Galesville for the sandstones underlying the Franconia and overlying the Eau Claire beds. They recognized the Franconia as a formation and restricted the St. Lawrence formation to include only the fossiliferous Lodi siltstone member and the Black Earth or St. Lawrence dolomite member. They suggested that the term Jordan be retained in a formational sense and discouraged the use of any further subdivisions on the basis that these subdivisions could be identified only in comparatively few sections.

During the preparation of the guidebook for the ninth annual Kansas Geological Society field conference in Iowa, Wisconsin and Minnesota[27] in 1935, several conferences occurred in an attempt to reach an agreement regarding the classification of the Cambrian. Complete agreement among all three states was not attained, but by conferences, correspondence and additional field work, a classification evolved which has proven to be the groundwork for a common classification of the Cambrian of the Upper Mississippi Valley. It differs from that of Trowbridge and Atwater in that it uses the term Trempealeau in a formational sense to include the St. Lawrence, Lodi, Jordan, and Madison sandstones as of equivalent member rank, but follows the Trowbridge and Atwater classification in the usage and subdivision of the terms Dresbach and Franconia. Twenhofel, Raasch and Thwaites[28] follow the Conference classification without exception.

In the most recent publications on the Cambrian of the Upper Mississippi Valley, Stauffer, Schwartz and Thiel[29] in 1939 and Stauffer and Thiel[30] in 1941 have revised the Minnesota classification in the light of more recent work. They follow Trowbridge and Atwater closely but substitute the Minnesota term Nicollet Creek for the term Black Earth, and subdivide the Jordan formation into the fine-grained, thin- to massive-bedded, dolomite-cemented Norwalk member below, and the coarse-grained, un-

[27] Trowbridge, A. C., and others, Kansas Geol. Soc. Guidebook 9th Ann. Field Conf., p. 18, 1935.

[28] Twenhofel, W. H., Raasch, G. O., and Thwaites, F. T., Cambrian strata of Wisconsin: Geol. Soc. America Bull., vol. 46, p. 1690, 1935.

[29] Stauffer, C. R., Schwartz. G. M., and Thiel, G. A., St. Croixan classification of Minnesota: Geol. Soc. America Bull., vol. 50, p. 1228, 1939.

[30] Stauffer, C. R., and Thiel, G. A., The Paleozoic and related rocks of southeastern Minnesota: Minnesota Geol. Survey Bull. 29, pp. 9, 30, 1941.

consolidated, massive Van Oser member above. For the area south of Redwing, Minnesota, the Minnesota equivalent of the Madison member of Wisconsin and Iowa is probably included in the Jordan and in other parts of Minnesota the Madison appears to be missing.[31]

DISTRIBUTION

Exposures of Cambrian strata in Iowa are limited almost entirely to Allamakee County in the northeast corner of the state. Oneota dolomite and younger rocks cap all of the upland, restricting the outcrop area of the Cambrian to the valley slopes and bottomlands. The boundary of the outcrop area shown on plate 1 is actually the line of intersection of the structure-contour map with the topographic map of the area. In cases where the point at which Cambrian beds disappeared below river level had been determined by traverses, this point has been used to determine the distance to which the outcrop area extends up the valley.

LITHOLOGY

Dresbach Formation

With one possible exception, members of the Dresbach formation do not outcrop in Iowa; the topmost beds normally occur below river level. In the vicinity of exposure 103, approximately midway between Lansing and New Albin, the Mississippi River valley cuts diagonally across a small anticline, and in the core of this structure approximately 2 feet of what is believed to be Galesville is exposed. At New Albin the top of the Galesville belongs somewhere within the 165 feet of valley fill penetrated by the city well, (described by Norton[32]), before the first rock stratum was entered. At Marquette, at the extreme south end of the area of outcrop, the top of the Dresbach occurs 330 feet below the river level. The discussion of members of the Dresbach formation must, therefore, be taken wholly from subsurface studies and must necessarily be less accurate and detailed than discussion relating to the upper formations.

Mt. Simon Member

The only information available on the Mt. Simon member is

[31]Trowbridge, A. C., Personal communication.
[32]Norton, W. H., Deep wells of Iowa: Iowa Geol. Survey, vol. 33, p. 280, 1928.

found in the rather generalized record of the first deep well at Lansing, reported to have passed completely through the Cambrian to enter the underlying crystalline rock. No properly preserved samples from this well are available but a tube made up from cuttings saved during drilling is in the hands of a resident of Lansing. Norton[33] examined this tube and prepared a generalized section, and during the course of work in the vicinity of Lansing, the writer examined the tube and prepared a section which agrees in its essential parts with that of Norton (see p. 418). The driller reports this well stopped upon entering "hard crystalline rock" which in this case must be taken to mean an igneous or metamorphic rock of pre-Cambrian age. If this is true, the Mt. Simon is 323 feet thick in this vicinity. The writer, however, could find no evidence to support the statement that crystalline rock was entered for the tube showed no igneous material at all. It is, therefore, believed that a thickness somewhat greater than 323 feet may be assigned to the Mt. Simon in this locality.

The Mt. Simon in this section is uniformly coarse-grained, fair- to well-sorted sandstone, clean except for four 7- to 10-foot bands of clay-coated sandstone distributed throughout. The sandstone varies from white to yellow to brown in color, and ranges from curvilinear to sub-round in shape. The grains are well-frosted and the unit bears no evidence of calcareous cementation or glauconite.

Eau Claire Member

The Eau Claire beds in the Lansing deep well are demarked above and below by sharp breaks in lithology. Though not exposed in the area studied, it is found at a depth of 291 feet below the curb of the Lansing well and is shown by the tube to be approximately 134 feet thick. Examination of the tube shows this member to consist of very fine-grained sandstone to siltstone, white to orange in color, and slightly micaceous and glauconitic. There was no evidence of fossils.

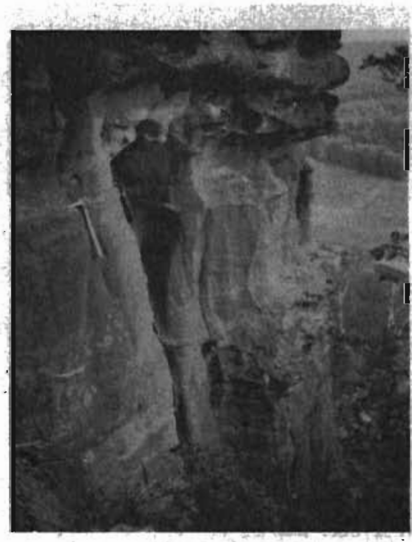
Galesville Member

The Galesville member is characteristically composed of medium-grained, clean, white sandstones and is defined as clean, unfossiliferous, unconsolidated sandstones, bounded above by the coarse- to very coarse-grained and sometimes fossiliferous sand-

[33]Norton, W. H., and others, Underground waters of the northeast district: Iowa Geol. Survey, vol. 21, p. 295, 1912.

A

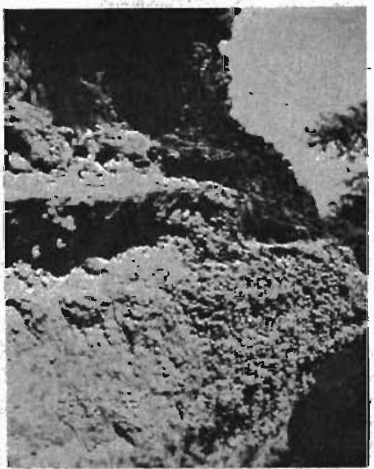
B



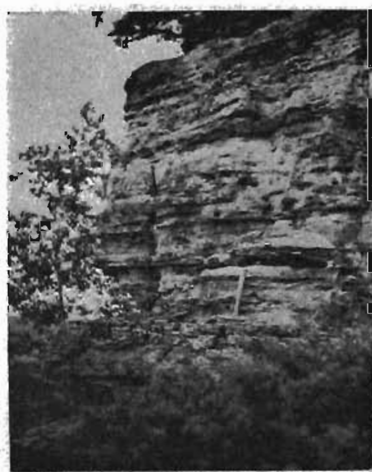
C

D

A. Ironton-Galesville contact, exposure 103.
B. Lodi siltstone, exposure 106, Fire Bell Hill, Lansing, Iowa.
C. Massive upper portion of the Jordan sandstone, exposure 38.
D. Ledgy character of the upper part of the Jordan sandstone, exposure 92.



A



B

C

D

A. Sand-calcite nodules in the upper part of the Jordan, exposure 9.
B. Madison sandstone, exposure 90.
C. Flattened cylindrical structures in the upper part of the Jordan sandstone in a bluff exposure in NE¼NW¼SW¼ sec. 22, T. 100 N., R 5 W.
D. Flattened cylindrical structures in upper part of Jordan sandstone, exposure 8.

stones of the Ironton member of the Franconia, and below by the fine-grained to silty, slightly glauconitic and fossiliferous sandstone of the Eau Claire member of the Dresbach. Both contacts may be gradational, making exact delimitation of the member difficult. The lower and middle portions of the Galesville are nowhere exposed in Iowa, but exposure 103, located near the axis of a structural high, shows 2½ feet of fine-grained, well-sorted, unconsolidated, massive sandstone, believed to be the upper 2½ feet of the Galesville, (see pl. 2, A) underlying 19 feet of coarse-grained, fossiliferous Ironton sandstone.

At Lansing, in the city well, the Galesville consists of 77 feet of clean, white, coarse-grained, well-sorted, unconsolidated sandstone, underlain by 17 feet of coarse- to very coarse-grained, unconsolidated sandstone. Of the upper 77 feet, a portion of approximately 20 feet must be allotted to the Ironton member of the Franconia since the overlying pale-green, micaceous siltstone or shale obviously belongs to the Goodenough member of the Franconia. The section thus interpreted comprises 74 feet of Galesville sandstone beginning at 217 feet below the curb of the city well.

At Marquette, in Clayton County, the Chicago, Milwaukee, St. Paul and Pacific Railroad well shows 90 feet of buff, medium- to coarse-grained, well-sorted, unconsolidated sandstone beginning 330 feet below the curb. Though thicker than the Galesville in the Lansing well, there is some doubt as to whether the complete thickness is shown here, since the drawing in of the Eau Claire contact is based solely upon the beginning of slight tendencies toward dolomitization.

At Waukon, a city well drilled in 1914 shows the Ironton and Galesville sandstones to fall between 780 and 870 feet below the well curb, but the exact range and lithology are unknown, since there are no samples for this interval.

Franconia Formation

The Franconia formation includes all beds from the base of the unnamed conglomerate member, underlying the St. Lawrence member of the Trempealeau formation, to the top of the clean, white, medium- to coarse-grained, unfossiliferous Galesville sandstone member below.

Though several exposures of the Franconia were found and described in the area studied, little could be done with regard to subdivision, since the entire sequence is a greensand succession containing virtually no fossils. In general, the Franconia in this area consists of fine-grained, well-sorted, angular sandstone, moderately glauconitic throughout and with occasional bands high in glauconite. Most exposures are fragmentary and so widely separated as to prevent any attempt to make a composite section on the basis of elevations. At Lansing, approximately 46 feet of section is exposed with 15 feet concealed between the lowermost St. Lawrence beds and the uppermost Franconia. The beds exposed undoubtedly belong in part to the Bad Axe member, and in part to the Hudson member, but the placing of the contact between these members without the aid of paleontological evidence is extremely hazardous. In exposure 89 (see p. 414), one thin dolomitized bed was found containing representatives of the *Prosaukia misa* faunule and the *Ptychaspis* faunule no. 5, both of which occur slightly below the middle of the Hudson, as indicated by Raasch,[34] who studied the specimens. On the basis of this evidence, the Bad Axe-Hudson contact has been tentatively placed between units 5 and 6. The Ironton and base of the Goodenough occur in exposure 103. The basal bed of the Goodenough is a fine-grained, glauconitic sandstone, well-sorted and slightly cemented in parts. The Ironton, in the single exposure examined, consists of 19 feet of medium- to very coarse-grained, very poorly sorted, unconsolidated sandstone (see pl. 2, A) with fragments and shells identified by Raasch as "*Parobolus littoralis*" from the *Cameraspis convexus* zone of the Ironton.

Underlying the Ironton in this exposure are 2 feet of white, fine-grained, nonfossiliferous sandstone believed to be Galesville. The contact between these two formations is sharp and distinct but there is no evidence of erosion.

A thickness of approximately 160 feet is obtained for the Franconia by interpolation between the Victory section described by Twenhofel, Raasch and Thwaites (in Wisconsin, directly across the Mississippi River from New Albin in the extreme northeast corner of Allamakee County, Iowa) and exposure 106 at Lansing.

Trempealeau Formation

The Trempealeau formation, and in particular the topmost members, the Jordan and Madison sandstones, form by far the

[34]Raasch, G. O., Personal communication.

major part of the available Cambrian exposures, and nearly every spur and ravine bed in the northeastern corner of Allamakee County exposes at least a portion of one or the other. The reason for this is that the upland is capped with very resistant dolomite, a circumstance which readily permits the formation of bluff exposures in the well-dissected country of the Driftless Area. Although complete sections of the Trempealeau are comparatively rare, a sufficient number occur to obtain an average figure for the thickness of this formation. At the Victory section, the Trempealeau is 173 feet thick. In exposure 106 at Lansing, it is 184 feet thick. At exposure 114 in the western half of Center Township, it is approximately 160 feet thick, and at Waukon, it is 150 feet thick. In the Trempealeau formation there is a pink dolomite at the base which grades upward through the Lodi siltstones to the fine-grained dolomitic siltstones and very fine-grained sandstones of the lower part of the Jordan, becoming progressively coarser until, at the top, the grain size is predominantly coarse-medium to coarse. In the overlying Madison, dolomitization increases upward and sand sizes again decrease and are predominantly fine-grained.

St. Lawrence Member

In the area studied, the St. Lawrence member is a fine to medium crystalline, glauconitic, sandy dolomite, 2 inches to 2 feet thick. It is commonly pink to red in color but lacks the purple splotched appearance present in adjoining states. The dolomitic band is underlain by 5 to 20 feet of thinly bedded, slightly dolomitic, sparsely glauconitic siltstones to very fine-grained sandstones which, however, do not contain the greensand conglomerate often occurring in the lower portion of the St. Lawrence in Wisconsin.

The member is bounded above by the thinly bedded and partially reworked basal siltstones of the Lodi member and is underlain by the Franconia greensands. The St. Lawrence is only rarely exposed in the area studied, but from the evidence available, both upper and lower boundaries are gradational.

Lodi Member

The Lodi member of the Trempealeau is characteristically siltstone, though it normally contains up to 30 percent of very fine sand grains and may contain up to 30 percent of dolomite. The member commonly ranges from 20 to 30 feet in thickness and consists of buff, slabby, thin-bedded, dolomitic siltstone to very fine-grained sandstone (see pl. 2, B). From top to bottom there is strikingly little variation in lithology and the only outstanding characteristic is the tendency toward reworked zones and occasional conglomeratic bands near the base. The Lodi occurs commonly in the lower one third of the valley slopes, so that exposures are uncommon and often fragmentary with top or bottom or both concealed. From the evidence available, however, it appears that both contacts are transitional for, at the top, the thin-bedded, slabby character of the Lodi gradually gives way to the more heavily bedded, blocky fractured, fine-grained, dolomitic sandstones of the base of the Jordan, and at the base, it grades within a very short distance through dolomitic siltstones to pink, glauconitic St. Lawrence dolomite. Supposedly fossiliferous, the Lodi yielded fossils only in exposure 106 atop Fire Bell Hill in Lansing where one specimen of the Trilobite *Dikelocephalus gracilis* Ulrich and Resser, was collected from near the base of the Lodi. In all other localities search for fossils proved fruitless. Laterally the Lodi shows virtually no variation.

Jordan Member

The Jordan member, lying transitionally between the Madison member above and the Lodi siltstone below, comprises the bulk of the Trempealeau formation. The term Jordan is of long standing but has been variously applied and interpreted by different writers. In the past, it has been considered as of formational rank, often rather indefinitely including the Madison beds and occasionly also the Lodi siltstones. In 1935, the classification prepared for the ninth annual field conference of the Kansas Geological Society[35] expanded the term Trempealeau to include Ulrich's Jordan (the present Van Oser facies) and Madison, reuniting the Norwalk and Van Oser facies and reducing the term Jordan to member rank. This has been generally accepted, except by Minnesota geologists, who prefer to retain the name Jordan in its formational sense because of its very widely established usage in that state.

Over the entire outcrop area of northeastern Iowa, the Jordan is remarkably uniform in thickness and lithology. It ranges from 100

[35]Trowbridge, A. C., and others, Kansas Geol. Soc. Guidebook, 9th Ann. Field Conf., p. 18, 1935.

feet to 120 feet thick and consists of two easily recognizable lithologies. The lower of these two, considered here as the Norwalk facies, is a fine- to very fine-grained buff to white sandstone, 60 to 80 feet thick. Dolomitic to the point of having well developed blocky fracture at the base, it grades upward to unconsolidated sandstone which in some beds is entirely massive and in others weathers to thin beds a quarter of an inch thick. Though fine-grained and very well sorted, it occasionally incorporates thin beds or stringers of coarse sand. Occasional thinly bedded zones may contain innumerable worm borings, but no fossil fragments have been identified. Local dolomitization may occur well up from the base, or slight cementation may extend upwards for a considerable distance. Both large and small scale cross lamination is well developed in many places.

Overlying this fine-grained sandstone and separated from it by a variable thickness of transition beds, is the Van Oser facies, a coarse-grained, well to poorly sorted, buff to brown sandstone, entirely unconsolidated except for secondary dolomitization in the form of ledges. This coarse facies ranges from 20 to 40 feet thick, is entirely barren of fossils, and is often completely massive except for large scale cross lamination which is common throughout (see pl. 2, C). Th upper 10 to 15 feet of the Jordan often has a very ledgy appearance occasioned by the selective deposition of secondary dolomite as cementing material along certain beds, while immediately adjacent beds above and below may be entirely unconsolidated. The mechanism of this deposition is not entirely clear, for while in many cases the cementation appears to have taken place along horizons of somewhat more perfectly sorted sandstone, permitting freer circulation of ground water, the reverse is also locally true, and dolomitization appears to have taken place within the more finely grained and occasionally slightly silty beds where circulation must certainly have been slower. This ledge-forming tendency manifests itself both in bluff and ravine exposures, and in some cases ledges may become very numerous and closely spaced (see pl. 2, D). Still another feature to be found in the selective dolomitization mentioned previously is the occurrence in a few exposures within a limited area around exposure 8 in the northeastern corner of Allamakee County, of a single horizon of dolomite-cemented ledges weathering out of the less consolidated sandstone as flattened cylinders, often in parallel arrangement (see pl. 3, C and D). As a possible explanation for these structures, the writer is inclined to believe that comparatively well-sorted coarse sands were swept into the troughs of a somewhat lithified, strongly ripple marked portion of the sea bottom, and that subsequent flow of mineralized ground waters has been directed along the resulting channels of greater permeability, with the result that dolomite cementation has been more active and has strongly cemented the more porous sand occupying the channel. Rarely, dolomitization may follow cross laminations, in which case a very odd reticulate structure is produced upon weathering. All of the dolomitization of the Van Oser facies is clearly of secondary nature and has very probably been derived by solution from the Oneota above. Where the Madison-Jordan contact is clearly distinguishable, ledges of silica-cemented sandstone occur rarely within the upper 1 to 2 feet of the Jordan. Since, as appears to be the case, such silica-cemented ledges occur only at the extreme top of the Jordan, they have, when present, been used to aid in placing the Madison-Jordan contact when other criteria are not so apparent.

Conglomerates are exceedingly rare, though one or two pebble stringers were found, and though uncommon, occasional green shale bands have been found to occur as much as 30 feet below the top of the Jordan. Where present, such green shale bands may range up to 3 inches in thickness but are invariably extremely local, pinching out in at least one direction within 15 to 20 feet. A further characteristic common to the coarse phase of the Jordan is the presence of numerous concretion-shaped spheres of calcite-cemented sandstone. These nodules appear to have developed by growth of crystalline calcite around a nucleus, enclosing sand grains as the aggregate grew. These sand-calcite nodules range from the size of a pea to more than a foot in diameter and weather out intact to form a very nodular surface (see pl. 3, A) and may be found in abundance at the base of the exposure if the sandstone is unconsolidated.

The lithologies described above are general in their occurrence and have been noted in both Wisconsin and Minnesota. The lower fine-grained portion is equivalent to the beds at Jordan, Minnesota to which Winchell[36] in 1874 originally applied that name.

[36] Winchell, N. H., The geology of the Minnesota Valley: Minnesota Geol. and Nat. History Survey 2d Ann. Rept., pp. 147-156, 1874.

The term Norwalk was applied by Ulrich[37] in 1924 to the same beds in Wisconsin, and this name has come into common usage. Four miles north of Jordan, Minnesota, on Van Oser Creek, may be found the coarse-grained sandstones overlying the Norwalk beds. The term Van Oser beds has come to be synonymous with the coarse-grained phase, and where the Jordan is considered as a formation, it is sometimes subdivided into the Norwalk and Van Oser members.

Though a sharp plane of division does not always exist between the Norwalk and Van Oser lithologies, they are undeniably distinct and invariably present in the area studied, and are commonly no less sharp than are boundaries between other members of the Cambrian system. The writer, therefore, feels the use of the terms Norwalk and Van Oser as members is entirely valid where the Jordan is considered as a formation. Where the Jordan is considered as a member, it does not seem advisable to subdivide it further so that the terms are used primarily in a descriptive sense in the present discussion.

Within the area studied, the Jordan is characterized by its lack of lateral variation, the only changes being a slight increase in the abundance of dolomitic ledges and a decrease in the occurrence of sand-calcite concretions southward along the Mississippi River. Westward along the Upper Iowa River there is little or no change.

The upper boundary of the Jordan is, for the most part the most clear-cut contact within the Trempealeau. Commonly it may be placed where the coarse-grained, massive, ledgy sands of the Jordan give way to the thin-bedded, conglomeratic, green shaly, basal beds of the Madison. Locally there may be a slightly undulatory surface with a relief of from 1 to 2 feet, but this is uncommon and, for the most part, the contact is horizontal and sharp. In Winneshiek County and the western part of Allamakee County this sharp line of demarcation fails and the Madison-Jordan contact is extremely difficult to establish.

The base is transitional, being placed as nearly as possible at the point where the rather massive, blocky, sandy-silty beds of the base of the Jordan give way to the thin-bedded siltstones of the Lodi member. Mechanical analyses show no change in composition across the boundary.

[37]Ulrich, E. O., Notes on new names in the table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin: Wisconsin Acad. Sci. Arts and Letters Trans., vol. 21, p. 83, 1924.

Madison Member

The Madison member consists of a series of fine-grained, thinly bedded, dolomitic sandstones lithologically distinct, both from the underlying Jordan sandstones and the overlying Oneota dolomite. These beds are placed in the Cambrian by Twenhofel, Raasch, and Thwaites[38] and in the Ordovician by Ulrich.[39] Though differing considerably from the beds of the type section at Madison, Wisconsin, the Madison beds of Iowa have been found without reasonable doubt to be equivalent, at least in part, to the beds of the type section. Field studies, insoluble residues and mechanical analyses all indicate they are transitional in nature and that no prominent break is present either above or below. Since this is the case, the Cambro-Ordovician boundary must be placed arbitrarily either at the top or at the base. Paleontologic evidence in adjacent areas indicates the Madison is of Cambrian age and the fact that the Madison sands are primarily sandstone, finer in grain and more perfectly sorted than the basal sands of the Oneota, incline the writer to the opinion that they should be placed with the Cambrian rather than the Ordovician.

Because of the abundance of exposures and variable lithology, a close study was made of this horizon in an attempt to determine the degree of variability and persistence of individual beds, and if possible to establish certain "marker" beds of value in subsurface studies.

In general, the lithology of the Madison is highly variable but certain features stand out as characteristic over considerable areas. Of these, one of the foremost is the thin-bedded character. In nearly all exposures in the eastern half of Allamakee County, beds range in thickness from a fraction of an inch to approximately 2 feet, commonly with all thicknesses represented in each exposure. Dolomite cementation along these bedding planes causes the rock to weather into a very characteristic ridge and valley type of surface (see pl. 3, B), often of considerable value in delimiting the member. Grain size, likewise, plays an important part in distinguishing the Madison from overlying and underlying beds. In general, the sand is fine-grained, grading to medium-grained in occasional individual beds and, in some exposures,

[38]Twenhofel, W. H., Raasch, G. O., and Thwaites, F. T., Cambrian strata of Wisconsin: Geol. Soc. America Bull., vol. 46, p. 1690, 1935.

[39]Ulrich, E. O., Notes on new names in the table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin: Wisconsin Acad. Sci. Arts and Letters Trans., vol. 21, p. 83, 1924.

grading to medium-grained toward the base. Alternations of grain size tend to distinguish beds and, within a single bed, to produce and emphasize cross lamination and to localize secondary calcite and dolomite cementation. The central portion of the Madison is characterized by an alternation of beds of buff, fine-grained, dolomite-cemented sandstone which weather to prominence and dark-gray, coarse-grained, well-sorted, unconsolidated beds which weather recessively, both 6 to 10 inches thick. Grain size was also found to vary laterally from fine to medium or from medium to coarse, in places occasioning an entire change of appearance within 10 to 15 feet.

A third important characteristic is the kind and amount of dolomite cementation. Both primary and secondary dolomite and secondary calcite are present. As the Madison-Oneota boundary is approached, dolomitization becomes more and more prominent, resulting in a distinctly blocky dolomitic fracture for the upper part of the member. After passing upward across the boundary, dolomite becomes predominant with sand grains subordinate and often "floating" in the dolomite. This dolomite is considered as primary and indicative of an increasing percentage of $CaMg(CO_3)_2$ deposition as Ordovician time began. In the central and lower portion of the Madison, dolomitization is selective, being concentrated along certain beds to the exclusion of others immediately adjacent, and often occurring as seams and partings following bedding planes and horizontal and cross lamination planes. Dolomitization of this sort is clearly a function of relative permeability of beds and horizons within beds and is of secondary origin. Calcite cementation is quite as common as dolomitization in some exposures, and appears to be entirely secondary.

Cross and horizontal lamination are common in all parts and exposures of the Madison. Where dolomitization is absent, truncation of cross-laminated and foreset beds are important in demarking bedding planes. Cross lamination may even appear occasionally in the strongly cemented upper portion of the member, indicating that perhaps at least a portion of this upper dolomite is secondary.

Characteristic of the Madison in the northeastern corner of Allamakee County and along the Mississippi River Valley southward to McGregor is the presence of numerous conglomerate zones. These conglomerates are predominantly of the thin flatflake variety, though occasional rounded or spheroidal pebbles occur. Few of the pebbles exceed half an inch in length and most of them are composed of pale-buff, fine-grained sandstone or siltstone, moderately cemented and firm. Most of the thin, flat flakes are oriented parallel to horizontal and cross lamination planes and bedding planes. They appear to be the result of the breaking up by occasional wave action of a thin, partly lithified layer of silty mud. Conglomerates of this nature may be limited to one or two beds, 8 to 10 inches thick, in which case they are apt to occur near the base, or they may be general throughout the entire lower portion of the member. In the upper portion, they are rare. In the opinion of the writer, there is nothing significant in these conglomerate zones as indicative of a time break, but rather that they perhaps indicate a restriction of the sea or at least a shallowing of the water with consequent increased effect by wave action.

Also characteristic of the Madison is the presence of occasional horizons carrying abundant green shale partings. The shale is leek green, dense and structureless with an irregular fracture, and these partings and seams of green shale, like the conglomerates, may be concentrated into a band 1 to 2 feet above the base, or may occur indiscriminately throughout the entire lower half of the Madison. They have not been observed in the upper portion of the unit, but occur rarely in the lower part of the overlying Oneota. Occasionally green shale pebbles may be found in the conglomerates, and often the flakes, oriented parallel to cross and horizontal laminations, are of green shale or the buff, weathered equivalent.

Locally, in one or two somewhat questionable instances, sand-calcite nodules and aggregates have been found in the lower portion of the Madison, but this is unusual and sand-calcite concretions may definitely be considered as a characteristic of the Jordan.

In the northeastern corner of Allamakee County, the Madison ranges from 18 to 22 feet in thickness, and maintains this thickness as far south as McGregor in northeastern Clayton County where the Cambrian sediments dip below river level. Westward, however, the aggregate thickness of beds recognizable as Madison decreases to as little as 3 feet in the western part of Allamakee County. Thicknesses, though consistently lower, seem quite variable in this region, and one of two alternatives is possible. The first is that the Madison is thinning westward, perhaps by pinching out and perhaps by erosion in this area. The second alternative is that the lower portion of the Madison changes in character westward, becoming identical with the underlying Jordan sands, thus making the placing of a contact between the two very difficult. The latter alternative is believed by the writer to be preferable for the following reasons: 1. The Madison-Oneota contact, everywhere gradational, is still present in the same appearance and relationship as seen in the northeastern part of the county. 2. The Jordan contact, comparatively definite and easily placed in the northeastern part of the county is, in the western part, the subject of considerable question wherever drawn. 3. Exposures have been found in the transition area showing the sands of the lower portion of the Madison becoming progressively coarser westward.

Accompanying the decrease in thickness of recognizable Madison beds westward from the Mississippi River, the member likewise undergoes a considerable change in character. In the western equivalent of the Madison, there are no green shale partings and no conglomerates. Sandstones are medium to coarse in grain size and may, as is the case in exposure 70 (see p. 411), show considerable regrowth of sand grains, giving an exposure a sparkling appearance in the sunlight. Bedding becomes more massive and dolomite cementation decreases. The transition from Madison to Oneota through a series of alternating sandy dolomites, dolomitic sandstones and thin sandstone stringers is, however, preserved.

Southward from the northeastern part of Allamakee County, the Madison increases in complexity, bedding is more diversified, green shale seams and partings are more common and conglomerates more numerous. There appears to be a tendency in the southernmost part of the area toward an increase in grain size of the lower part of the section, but green shale zones and conglomerates clearly mark the base of the Madison.

As more and more sections were studied it became apparent that no single "marker" bed could be found. Occasionally one horizon could be traced for 1 or 2 miles but could not be identified over any considerable area. Beds changed in character radically within the space of a single outcrop, and it was concluded that only the more general characteristics such as thin bedding, fineness of grain, and type and degree of cementation are common to the entire area studied.

Cambro-Ordovician Boundary

Since the Cambro-Ordovician line in Iowa is entirely transitional, it becomes necessary, more or less arbitrarily to select an horizon identifiable over a considerable area. After several sections had been described in detail, and considerable reconnaissance work had been done in several parts of the area, such an horizon was selected and was found to work surprisingly well throughout the area.

In general, the lower portion of the Oneota is characterized by a diversity of lithology. Sandy dolomites and dolomitic sandstones with occasional bands of clean, unconsolidated sandstone are the normal lithology. Sandstones were found, in general, to be more coarsely grained and more poorly sorted than those of the underlying Madison sandstones. Highly oolitic beds and some sparsely glauconitic zones are also common. In some exposures, *Cryptozoon* reefs occur from 5 to 10 feet above the base. These, however, are found only in a limited number of cases and are therefore of little value in establishing boundaries. Since beds of a transition zone are subject to lateral variation, it is not to be expected that a single bed or a single characteristic can be used for reference successfully over any considerable area. Rather, each contact must be judged individually, and to this end a set of criteria for Oneota and Madison beds were formulated as follows: 1. Unless very clearly unadvisable, the boundary was placed below the lowest good dolomite or sandy dolomite. This rule was violated not more than twice in the 147 exposures studied. 2. Oolitic and glauconitic beds were invariably considered as belonging to the Oneota. 3. *Cryptozoon* beds were rather loosely considered to be 5 to 10 feet above the base of the Oneota. 4. Strongly dolomite-cemented sandstones with blocky fracture were usually considered as Ordovician unless cross laminated, in which case they were placed in the Madison.

Usually not one criterion but a combination of several were used in placing the boundary, and the reliability of the contact thus selected is shown by the uniformity of the thickness of the Madison throughout the entire eastern half of Allamakee County.

STRUCTURE

During the course of field study, a series of altimeter traverses were run throughout the area. Levels were run from these traverses to all described sections so that elevations are available for nearly all exposures. These elevations, plotted as a structure-contour map on the Cambro-Ordovician contact (see pl. 1), reveal a surprising amount of structure for such a limited area on sediments believed to be, for the most part, undisturbed. A study of plate 1 shows four distinct structural highs trending approximately northwest-southeast. Of these, the southeasternmost is the highest with a relief of 120 feet. The second, in the northeast corner of Allamakee County, is 80 feet high. Because of the irregular distribution of exposures which were restricted to stream valleys, there occur certain areas where control is insufficient. Contours in these areas have been drawn in as dashed lines, in what appeared to be the most logical interpretation on the basis of the facts available. Because of the irregular nature of the distribution of points, more than one interpretation is possible for some localities, and the map is presented as tentative and subject to correction and revision as information increases.

LABORATORY STUDIES

Technique

During the course of field work, important sections were sampled by channeling methods, and the samples were further studied in the laboratory. Over 500 samples were collected and studied. Individual samples were taken from each unit unless the unit exceeded 5 feet in thickness, in which case it was divided into uniform 5-foot channel samples.

Experimentation showed that coarse crushing provided insufficient surface area to remove rapidly the comparatively insoluble dolomite so that fine crushing was found to be necessary to facilitate the removal of carbonates. To this end, all samples were passed through a series of crushers consisting of a jaw crusher, a set of rolls, and a disc crusher in the order named. All samples were crushed approximately to the size of the largest grains since the nature of the dolomite permitted crushing to this size without undue crushing of quartz grains. The sample was then split on a sample splitter to approximately 100-150 grams. Following this, samples were covered with water and concentrated commercial hydrochloric acid was added as rapidly as possible without undue effervescence and foaming until the reaction was complete. This commonly took from two to four hours and an additional two hours was allowed to remove the last traces of dolomite. After samples had been permitted to settle until the supernatant liquid was clear, the acid was drawn off by means of a suction pump and the beakers were filled with clear water and permitted to settle again. This flushing action was repeated six times after which nearly all soluble matter and acid had been removed from the sample. Samples were then dried and reweighed to obtain the loss of weight, that is the weight of soluble material present in the original sample. Each sample was then run through a set of screens selected to correspond with Wentworth's size grade scale.[40] All samples were shaken for 20 minutes in a mechanical shaker and then each individual fraction was weighed to determine relative percentage of the several size grades.

Results were plotted as bar graphs on the basis of the weight of the original sample. That is, the percentage of soluble matter was plotted on the left side as a portion of the total. These bar graphs were plotted one above the other in the form of a geological column for each exposure so that cross sections showing lateral and vertical changes in grade size could be constructed. Two such cross sections were made, one showing lateral changes westward from the Mississippi River along the Upper Iowa River to the west edge of Allamakee County (see pl. 4), and the other showing variations southward from the northeastern corner of the county south to McGregor in northeastern Clayton County (pl. 5).

Discussion

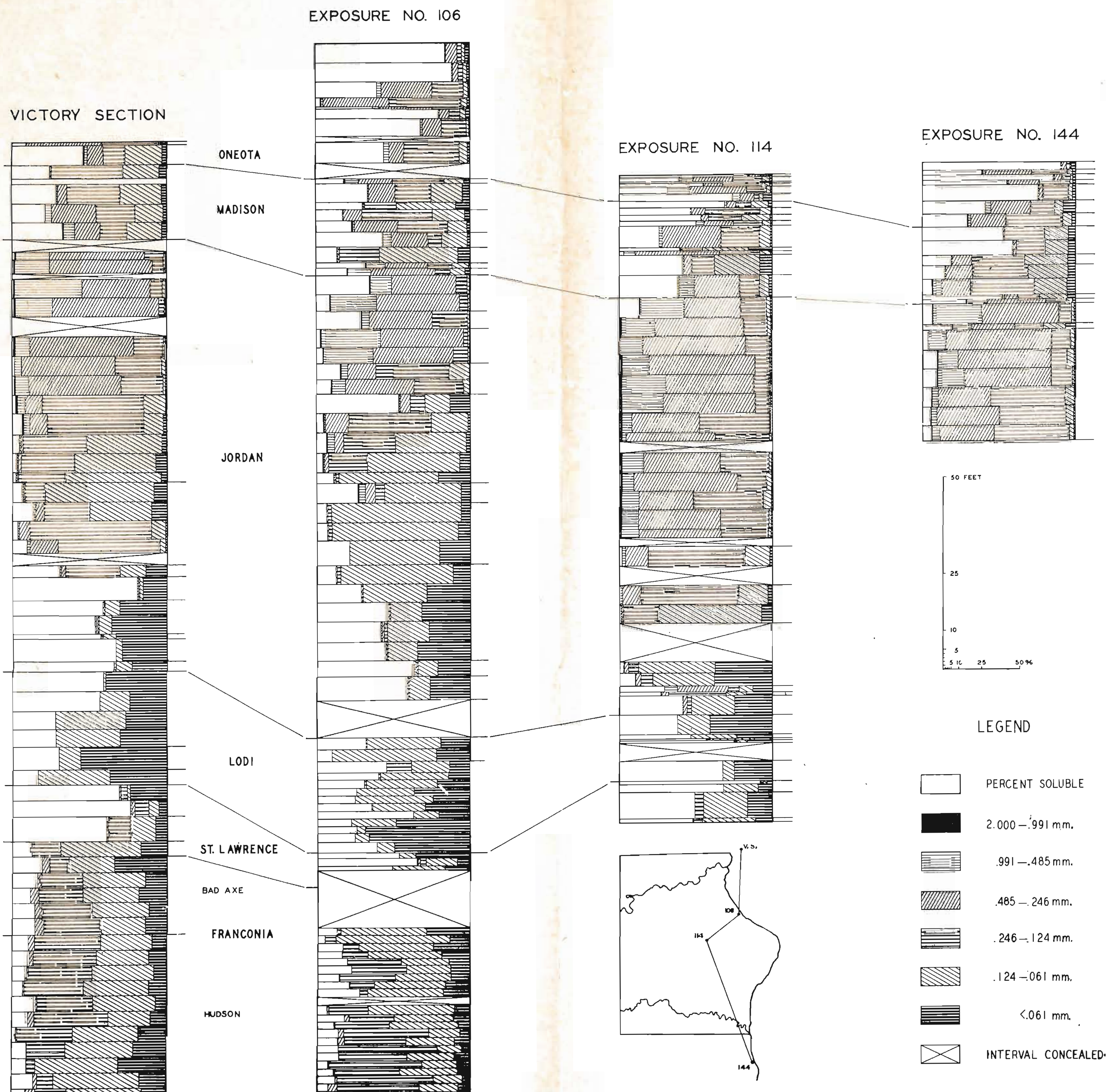
The purpose of mechanical analyses of these sandstones was twofold; first, to see if by mechanical analysis studies a set of criteria could be obtained which would be of value in correlating small isolated exposures showing no contacts; and secondly, to bring out more clearly the transitional nature of contacts within the Cambrian and the approximate size ranges of each member.

The Victory section, located in Wisconsin across the Mississippi River from New Albin, Iowa and described by Twenhofel, Raasch and Thwaites[41] in 1935, has been included in both cross sections

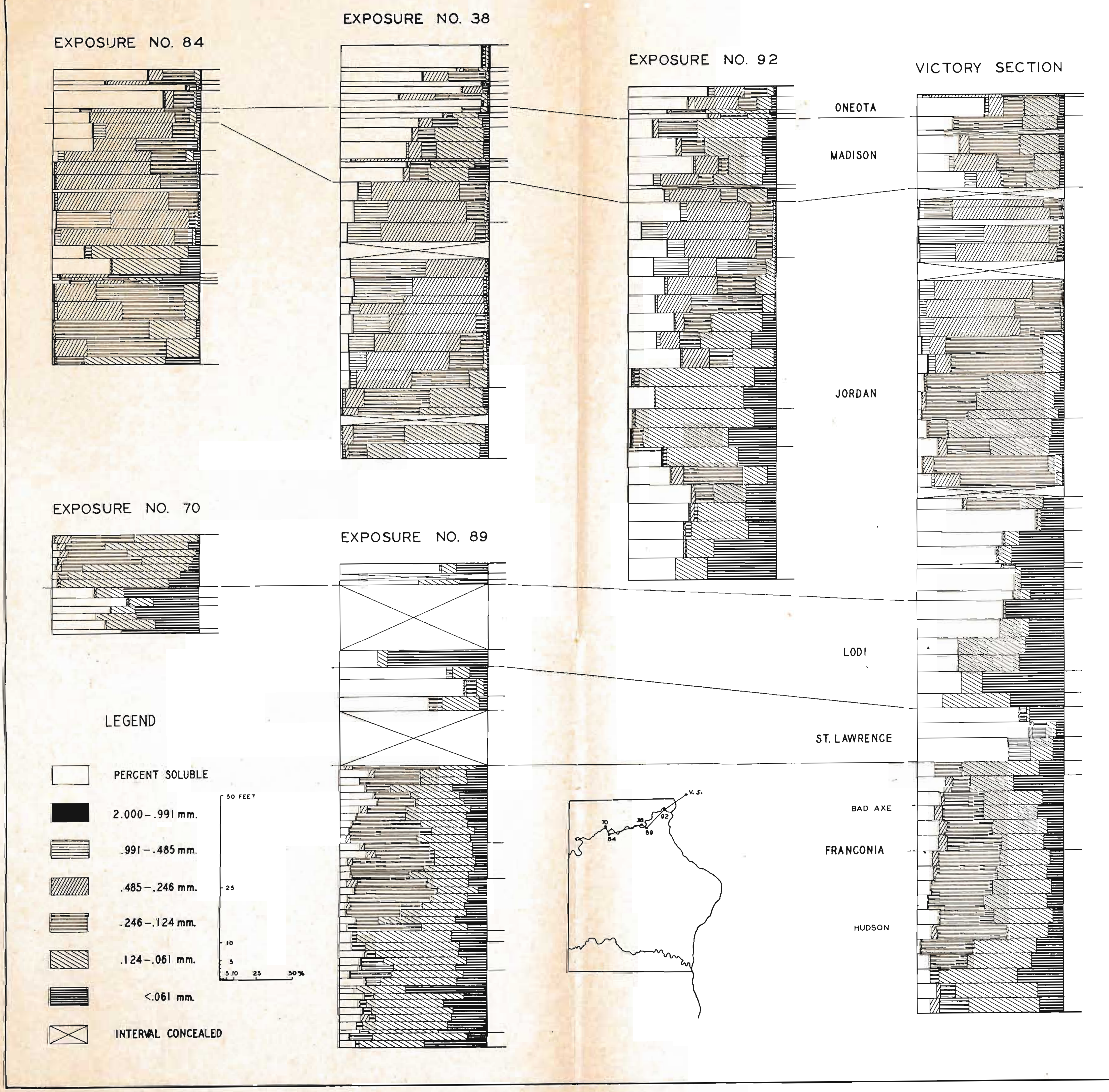
[40] Wentworth, C. K., Methods of mechanical analysis of sediments: Iowa Univ. Studies in Nat. History, vol. 11, no. 11, p. 24, 1926.

[41] Twenhofel, W. H., Raasch, G. O., and Thwaites, F. T., Cambrian strata of Wisconsin: Geol. Soc. America Bull., vol. 46, p. 1690, 1935.

CROSS SECTION SHOWING INSOLUBLE RESIDUES AND MECHANICAL ANALYSES



CROSS SECTION SHOWING INSOLUBLE RESIDUES AND MECHANICAL ANALYSES



as an "anchor section," since it is both long and very nearly complete.

A study of plates 4 and 5 reveals a number of interesting characteristics of each member. The Franconia formation is characterized by its uniformity throughout, running 70-80 percent fine to very fine sand, with 10-20 percent silt, 10-15 percent dolomite, and 1-5 percent medium sand. There appears to be no change whatever in grain size or percentage of dolomitization from Hudson to Bad Axe in the Victory exposure which, in this case, has been drawn almost entirely on paleontologic evidence. Passage from the Franconia to the St. Lawrence is marked by a considerable increase in the percentage of dolomite present, the latter being 60-80 percent soluble. Near the middle of each exposure of the St. Lawrence, a horizon was found which contained 1-2 percent of coarse sand. Otherwise only fine sands to silts are present in addition to the soluble material. Passage upward into the Lodi is marked by a slight decrease in dolomitization, but primarily by a definite and appreciable increase in silt percentage. In general the member averages 30 percent dolomite, 30-40 percent silt and 20-30 percent very fine sand.

Of the formations and members of the Cambrian the Jordan is the thickest and most varied. The member consists in the lower 25-35 feet of over 50 percent dolomite, 40-45 percent silt and only 1-5 percent fine and very fine sand. Above this a very regular gradation may be traced from very fine sand below to medium to coarse sand at the top. This gradation is best shown by exposure 38 (pl. 4), but may be identified in each of the sections shown. The upper portion of the Jordan is further characterized by almost complete lack of dolomite cement though in some sections the presence of dolomite-cemented ledges and sand-calcite nodules belies this statement. Only in the Van Oser beds of the Jordan is there any appreciable coarse and very coarse sand. The Jordan-Madison contact is marked by a well-defined change in grain size, from predominantly medium grading to coarse below, to more or less equally distributed fine-medium, fine and very fine sand with coarse sand distinctly subordinate, and a marked increase in dolomitization. The contact between the Madison and Oneota is much less well defined as is the case in field studies. There is a gradual increase in the amount of dolomitization and a marked increase in the percentage of medium-grained sand at the expense of fine- to very fine-grained sandstone.

The writer wishes to emphasize again the statement that the greatest value of these plates lies in clearly showing the gradational nature of changes in grain size and the gradational nature of formational and member boundaries in the Cambrian.

APPENDIX

Geologic Sections

Exposure 38

Location: Extreme NE¼SW¼NW¼ sec. 31, T. 100 N., R. 4 W. Exposure on west face of isolated knob immediately northeast of bridge in sec. 31.

	Feet
Ordovician system	
Oneota formation.	
15. Dolomite, light buff, highly coarse sandy to sandstone, fine-grained, very dolomitic. Unit is hard and compact	2.8
14. Dolomite, light gray subcrystalline, very hard, with small *Cryptozoon* structures throughout	1.4
13. Dolomite, drab, finely crystalline, sandy, green-flecked, hard	2.0
12. Sandstone, brown, medium-grained, dolomite-cemented; with slight development of nodular surface characterized by presence of sand-calcite concentrations	1.8
11. Dolomite, light drab, very finely crystalline, compact to porous	2.0
Cambrian system	
Trempealeau formation	
Madison sandstone member:	
10. Sandstone, brown, very dolomitic, firm	1.2
9. Sandstone, buff to light brown, very fine-grained, hard, with sharp angular-weathering fragments	1.5
8. Sandstone, light drab, very dolomitic and grading to dolomite, very sandy, poorly sorted, very hard	2.5
7. Sandstone, pale buff, fine-grained, unconsolidated, well-sorted, friable, thin-bedded. Lower 4.5 feet show dolomitization along bedding planes and lateral gradation into thinly interlaminated sandstone and siltstone	8.7
6. Sandstone, buff, coarse-grained, well-sorted; conglomeratic with thin flat pebbles	0.7
(section transferred to south half of bluff)	
5. Sandstone, light brown, very fine-grained, well-sorted; innumerable worm borings, very irregular appearance	1.5
4. Sandstone, buff, fine- to very fine-grained with thinly interlaminated bands of siltstone or shale and 2 to 3 inch bands pinkish dolomite-cemented sandstone. Numerous worm borings. Numerous shale seams in lower 1 foot	3.6
Jordan sandstone member:	
3. Sandstone, buff to light buff, irregularly interbanded, medium-grained, unconsolidated, subangular sandstone and coarse grained, subround, well-frosted, strongly calcite-cemented sandstone. Slight local development of nodular weathering surface	11.0
2. Sandstone, buff, coarse-grained, well-sorted, unconsolidated except for occasional 2 to 3 inch hard calcite-cemented ledges	45.0
1. Sandstone, white to very light buff, fine- to very fine-grained, unconsolidated, friable	19.0

Base of section is 806 feet above sea level.

Exposure 70

Location: SE¼NE¼NW¼ sec. 6, T. 99 N., R. 5 W. Exposure on spur and road cut.

Ordovician system	
Oneota formation	
14. Dolomite, light drab, medium crystalline, hard, numerous cavities	13.0

		Feet
13.	Dolomite, sandy grading in part to dolomitic sandstone, light drab, fine to coarse sandy, poorly sorted, hard, in beds 8 to 16 inches thick. Lower 5 feet is very highly sandy	11.0

Cambrian system
Trempealeau formation
Madison sandstone member:

12.	Sandstone, light buff, medium to coarse-grained, interbedded angular coarse-grained sandstone and well-rounded and frosted sandstone, calcite-cemented and very ledgy in appearance	6.8

Jordan sandstone member:

11.	Sandstone, light buff, coarse-grained, fair sorting, strongly calcite-cemented, ledgy. Sand-calcite concretions common locally	23.0
10.	Sandstone, light buff, fine-grained, very well sorted, somewhat cross-laminated and with well developed horizontal fine banding. Occasional stringers coarse-grained sandstone with accompanying sand-calcite concretions. Unit grades to medium-grained at top	24.0
9.	Concealed	21.0
8.	Sandstone, pale buff, fine- to coarse-grained, poorly sorted, strongly calcite-cemented, ledgy	2.5
7.	Sandstone, very pale buff, fine-grained, very well sorted, unconsolidated, massive	5.5
6.	Concealed	11.0
5.	Sandstone, white to buff, fine-grained, very well sorted, entirely unconsolidated except for numerous sand-calcite concretions, horizontally bedded, cross-laminated in parts, occasional green bands in upper part becoming more numerous with depth. Unit becomes more thin-bedded with depth	15.5

Lodi siltstone member:

4.	Siltstone, buff, coarse-grained, soft, thinly-bedded, massive	3.0
3.	Siltstone, buff, coarse-grained, thinly bedded, strongly calcite-cemented	2.0
2.	Siltstone, buff, very fine-grained, very thin-bedded with well developed shaly appearance and occasional thin dolomitized bands. Innumerable green shale partings throughout	6.3
1.	Siltstone, bluish-gray, weathering to buff, very fine-grained, subconchoidal fracture	1.3

Base of section is 687 feet above sea level.

Exposure 84

Location: NE¼SE¼SE¼ sec. 6, T. 99 N., R. 5 W. Exposure in bed of ravine approximately 900 yards west along the south side of Upper Iowa River Valley from point where north-south town road climbs out of valley.

Ordovician system
Oneota formation

15.	Dolomite, drab to light drab, medium to finely crystalline, hard	10.0
14.	Dolomite, buff, very sandy to sandstone, very dolomitic, oolitic in parts; sand is medium- to coarse-grained	3.0
13.	Sandstone, light buff, medium- to fine-grained, well-sorted, angular unconsolidated	1.0
12.	Dolomite, light drab, medium crystalline, composed of euhedral crystals, porous, hard, very irregular structure	1.7
11.	Dolomite, drab to light drab, hard, medium crystalline, slightly sandy, blocky fracture; becoming strongly sandy at base	4.5

Cambrian system
Trempealeau formation
Madison sandstone member:

10.	Sandstone, buff, medium- to coarse-grained, soft, numerous green shale or siltstone bands	1.1

	Feet
9. Sandstone, buff, medium- to coarse-grained, fair sorting, occasional to numerous large masses of fine crystalline quartz	2.8
Jordan sandstone member:	
8. Sandstone, buff to light brown, coarse- to very fine-grained, poorly sorted with interstices filled with silt, unit very strongly calcite-cemented and ledgy 6 feet from top. Numerous sand-calcite concretions in parts	7.7
7. Sandstone, buff to light brown medium-grained, fairly well sorted, unconsolidated, ledgy, in beds 1 to 3 feet thick with buff-weathered, silty, thinly bedded sandstone partings	6.5
6. Sandstone, light brown, medium- to coarse-grained, well sorted, unconsolidated. Large scale cross lamination	19.5
5. Sandstone, buff, fine-grained, well-sorted, very thinly horizontally bedded, unconsolidated; numerous worm borings in some beds	7.7
4. Siltstone, olive buff, very thinly laminated, plastic when moist	1.0
3. Sandstone, brown, fine-grained with sprinkling of coarse, very thinly bedded	0.7
2. Conglomerate zone, large boulders (1 to 2 feet diameter) of coarse-grained sandstone strongly cemented by calcite, in matrix of coarse unconsolidated sand	1.0
1. Sandstone, light brown, fine-grained, well-sorted, unconsolidated, massive. Numerous worm borings in some beds	22.0

Base of section is 737 feet above sea level.

Exposure 88

Location: North center SE¼SE¼ sec. 6, T. 99 N., R. 4 W. Exposure in west wall of main valley approximately two-thirds of a mile southeast along valley from mouth.

	Feet
Cambrian system	
Trempealeau formation	
Jordan sandstone member (?):	
8. Dolomite, buff, or siltstone, hard, in massive beds at base becoming thin-bedded in upper 1½ feet	3.5
Lodi siltstone member:	
7. Siltstone, buff, fine-textured, very thin-bedded, poorly exposed	15.0
6. Siltstone to shale, light buff to dark olive green, very thin-bedded with very irregular fracture, soft	3.0
St. Lawrence dolomite member:	
5. Sandstone and siltstone interbanded, light buff, thin-bedded, occasional highly glauconitic bands, dolomite-cemented, weathering to resistant ledge	2.5
4. Greensand conglomerate, matrix fine- to medium-grained sandstone; pebbles buff, fine-grained sandstone	0.7
3. Dolomite, drab to pinkish, medium crystalline, highly glauconitic throughout, hard, weathers to slabs, 1 to 3 inches thick	2.7
2. Sandstone, brown, fine-grained, well-sorted, moderately glauconitic throughout, weathers to massive ledge with 1 to 2 inch bedding planes, dolomite-cemented, hard	5.0
Franconia formation:	
1. Sandstone, light buff, fine-grained, angular, well-sorted, glauconitic throughout, very thin-bedded, unconsolidated and highly glauconitic in upper 5 feet. Occasional thin dolomite-cemented bands. Greensand conglomerate 3 feet above base	18.0

Base of exposure is approximately 665 feet above sea level, determined from topographic map.

Exposure 89

Location: Center NW¼SW¼ sec. 32, T. 100 N., R. 4 W. Exposures on crest of knob directly north of school house, on west slope of knob, in road cut on west slope of knob, and in stream bank across creek from knob.

	Feet
Cambrian system	
Trempealeau formation	
Jordan sandstone member:	
15. Siltstone or fine-textured dolomite, buff, homogeneous, in slabby beds 1 to 3 inches thick	2.5
14. Concealed	1.5
13. Sandstone, light buff, fine-grained, silty, mottled, dolomite-cemented and ledgy	1.5
Lodi siltstone member:	
12. Concealed	18.0
11. Siltstone, buff, homogeneous, very thin-bedded. Traces of gray, nonfissile siltstone in lower 3 feet. Exposed only as rubble on slope	5.0
St. Lawrence dolomite member:	
10. Dolomite, buff to pinkish buff, green-speckled with glauconite, medium crystalline, sandy, hard, in slabs 2 to 3 inches thick	8.0
9. Sandstone, buff, fine-grained, well-sorted, in parts strongly mottled with buff siltstone, strongly cemented	4.0
8. Concealed	15.0
Franconia formation	
Bad Axe member:	
7. Sandstone, light buff to greenish, fine-grained, well-sorted, moderately glauconitic with occasional highly glauconitic bands, unconsolidated at base but becomes bedded and blocky in upper two-thirds	21.0
6. Sandstone, dark green and light buff interlaminated, fine-grained, well-sorted, occasional thin-bedded buff siltstone beds in upper part. Some bands dark red from iron cementation	10.0
Hudson member (?):	
5. Sandstone, shaly, dark gray to green strongly mottled with light gray, very fine-grained, highly glauconitic, soft, very thin-bedded. Mottlings are of light gray siltstone or shale. Two bands buff, fine-grained sandstone to siltstone, thin-bedded, slabby, hard, with gray siltstone partings; one 1.5 feet thick and 1.3 feet above base, second is 6.2 feet above base and 1.8 feet thick. Lower band carries one ½ inch highly fossiliferous zone (*Prosaukia misa* faunule and *Ptychaspis* faunule No. 5)	14.0
4. Sandstone, buff, fine-grained grading to siltstone in upper part, hard, thin-bedded	3.0
3. Siltstone, gray, micaceous, thinly interlaminated with dark green glauconite bands and buff, fine-grained, glauconitic sandstone bands. Color dark gray to green	7.5
2. Sandstone, very fine-grained, buff, and siltstone, very thin-bedded, shaly, interbedded. Slightly cemented, slightly blocky fracture in parts. Numerous bands greensand	12.0
1. Sandstone, very fine-grained with numerous slate gray shale partings giving unit gray- to bluish-gray color, very thin-bedded	4.0

Base of exposure is 650 feet above sea level.

Exposure 92

Location: West center SE¼SE¼ sec. 15, T. 100 N., R. 4 W. Exposure on first prominent knob south of Upper Iowa River and west of Mississippi River.

	Feet
Ordovician system	
Oneota formation	
19. Dolomite, drab, medium to finely crystalline, hard, coarse sandy and oolitic at base	26.0

		Feet
18.	Sandstone, buff, medium- to coarse-grained, fair sorting, strongly cemented	0.5
17.	Concealed	1.0
16.	Sandstone, buff, medium- to coarse-grained, fair sorting, strongly cemented (possibly not in place)	1.0
15.	Sandstone, buff, fine- to coarse-grained, poorly sorted, unconsolidated, massive	0.5
14.	Dolomite, light drab, finely crystalline, very porous, hard	1.1
13.	Sandstone, buff, fine- to coarse-grained, poorly sorted, very strongly cemented and grading locally into dolomite	1.8
12.	Sandstone, buff, coarse-grained, very strongly dolomite-cemented	1.5
11.	Sandstone, light buff, fine-grained, well-sorted, unconsolidated, massive, weathers gray on surface	1.0
10.	Sandstone, buff, fine- to coarse-grained, strongly dolomite-cemented	1.4

Cambrian system
Trempealau formation
Madison sandstone member:

9.	Sandstone, very light buff, fine-grained, well-sorted, slightly conglomeratic in upper 1 foot and again in bottom 1 foot, massive, unconsolidated in upper 4 feet and again near base. Central portion consists of thin slightly cemented beds with cementation concentrated along bedding planes. Cross lamination prominent	18.0
8.	Sandstone, white, fine-grained, similar to overlying unit but unconsolidated	1.0
7.	Sandstone, very pale buff, fine- to coarse-grained, poorly sorted, calcite-cemented and with strong development of sand-calcite concretions on weathered surface. Conglomeratic in lower part	3.7

Jordan sandstone member:

6.	Sandstone, buff, medium- to coarse-grained, moderately to poorly sorted, unconsolidated but with considerable interstitial dolomite, slightly conglomeratic	15.0
5.	Sandstone, light buff, fine-grained, well-sorted, unconsolidated	41.0
4.	Sandstone, very pale buff, fine-grained, unconsolidated, massive, weathers gray on surface	10.5
3.	Sandstone, buff, fine-grained, strongly dolomite-cemented, ledgy, rather thin-bedded and only slightly cemented in lower two-thirds, worm borings abundant. Zone of flattened cylinders at top	36.0
2.	Concealed	149.0

Franconia formation:

1.	Sandstone, light buff, fine-grained, well-sorted, angular, moderately glauconitic throughout, unconsolidated, in beds 1 to 2 feet thick with 2- to 5-inch bands of dark green, highly glauconitic sandstone between. Beds weather to finely mottled appearance	8.5

Base of exposure is 698 feet above sea level.

Exposure 106

Location: SW¼SW¼SE¼ sec. 29, T. 99 N., R. 3 W. Exposure on south-trending spur of Mt. Hosmer directly north and adjacent to Lansing, Iowa.

Ordovician system
Oneota formation

		Feet
28.	Sandstone, buff to white, medium- to coarse-grained, poorly sorted, strongly dolomite-cemented, irregularly fractured and very irregularly weathered in upper part, basal 22 feet predominantly coarse, very dolomitic sandstone to very sandy dolomite	35.0

		Feet
Cambrian system		
Trempealeau formation		
Madison sandstone member:		
27.	Sandstone, gray, medium-grained, fair sorting, slightly dolomite-cemented, hard	1.0
26.	Sandstone, very light buff, fine-grained, well-sorted, slightly dolomitic, firm, thin-bedded	7.0
25.	Sandstone, very light buff, medium- to coarse-grained, fair sorting, occasional worm holes, somewhat pebbly, partially cemented, massive	6.0
24.	Sandstone, light buff, fine-grained, well-sorted, thin-bedded, cross-bedding prominent, very strongly dolomite-cemented	4.0
23.	Sandstone, white, fine-grained, very well-sorted, unconsolidated, weathered gray on surface	4.0
22.	Sandstone, light brownish buff, similar to underlying unit but strongly dolomite-cemented, hard	1.1
21.	Sandstone, light buff, medium- to very coarse-grained, poorly sorted, unconsolidated, conglomeratic with thin flat flakes, slightly shaly in lower part	2.0
Jordan sandstone member (Exposed in road cut below Strong's Point).		
20.	Sandstone, light buff, medium- to coarse-grained, fairly well sorted, grading down within 1½ feet to light buff, coarse-grained, very well-sorted, massive, unconsolidated sandstone	9.3
19.	Sandstone, light brown, similar to overlying unit but strongly calcite-cemented	4.5
18.	Concealed	2.7
17.	Sandstone, light buff, coarse-grained, well-sorted, massive and unconsolidated except for occasional strongly calcite-cemented ledges	9.0
16.	Sandstone, buff, coarse- to fine-grained, poorly sorted, slightly dolomitic but unconsolidated; transitional to finer beds below	8.0
15.	Sandstone, light buff, medium-grained at top, grading rapidly to fine-grained, very well sorted, unconsolidated	23.0
14.	Sandstone, light buff, fine-grained, very well-sorted, similar to overlying unit but strongly dolomite-cemented, in blocky beds 4 to 12 inches thick. Strongly conglomeratic in upper 1 foot	5.0
13.	Sandstone, light buff, very fine-grained, similar to overlying unit but unconsolidated, massive	16.0
12.	Sandstone, light buff, very fine-grained, very well-sorted, dolomite-cemented, firm, massive beds at top grading to thin-bedded and more dolomitic toward base. Beds ½ to 3 inches thick at base	25.0
11.	Sandstone, light buff, very fine-grained, very well-sorted, strongly brown mottled with dolomite, thin-bedded, hard	4.2
10.	Sandstone, light buff, very fine-grained, to siltstone, very well-sorted, firm, unconsolidated, thin-bedded	6.0
9.	Concealed (To top of Fire Bell Hill exposure)	7.7

Exposure 106 Continued

Fire Bell Hill Exposure

Location: SW¼NE¼SE¼ sec. 29, T. 99 N., R. 3 W. Exposure in Lansing, Iowa, on south end of Fire Bell Hill facing south on the alley north of Main Street one-half block west from Second Street.

		Feet
Lodi siltstone member:		
8.	Sandstone, light buff, very fine-grained, very well-sorted, firmly dolomite-cemented at surface becoming unconsolidated within. Weathered massive	6.0
7.	Sandstone, light buff, very fine-grained, and siltstone; unit consists of thinly interlaminated dolomite-cemented and uncemented bands; conglomerate zone 5 feet below the top	13.0

	Feet
6. Conglomerate, a reworked zone consisting of angular to rounded siltstone pebbles in a highly contorted matrix of similar material; strongly dolomite-cemented in parts	2.0
5. Sandstone, buff, olive in fresh fragments, very fine-grained sandstone to siltstone, very thinly bedded weathering to shaly appearance on weathered surface, siltstone predominant in lower two-thirds	8.0
St. Lawrence dolomite member:	
4. Sandstone, buff, and siltstone, similar to overlying unit but dolomite-cemented and ledgy. Two conglomerate zones near the middle	1.3
3. Sandstone to dolomite, glauconitic, hard, sandstone, fine-grained, well-sorted, strongly dolomite-cemented and grading to dolomite in part, conglomeratic	3.0
2. Concealed	15.0
Franconia formation	
Bad Axe and Hudson sandstone members:	
1. Sandstone, light buff, fine-grained, very thin-bedded, slightly cemented, moderately glauconitic throughout and with occasional highly glauconitic zones	46.0

Base of exposure is 670 feet above sea level.

Exposure 114

Location: NE¼ & SW¼SE¼NE¼ sec. 20, T. 98 N., R. 4 W. Two exposures, the upper located in a ravine back of the farm, on west side of road, and the lower in road cut on west side of road immediately north of farm buildings.

	Feet
Ordovician system	
Oneota formation	
33. Dolomite, yellowish buff, finely crystalline, medium to coarse sandy, oolitic, moderately hard	0.5
32. Sandstone, buff, medium- and coarse-grained, fairly well-sorted, dolomitic but weak and friable, grading to white at base	1.2
31. Dolomite, buff to light greenish, subcrystalline, fine to coarse, sandy, sand very poorly sorted	0.3
30. Sandstone, buff, very highly dolomitic, to dolomite, very sandy, sand fine-grained, very well-sorted	0.6
29. Sandstone, brown buff, medium- to coarse-grained, very highly dolomitic but weathered to weak friable condition, sand fairly well-sorted	1.7
28. Dolomite, buff to pinkish, finely crystalline, moderately hard, fine to coarse sandy, conglomeratic	0.3
27. Dolomite, bluish gray, very finely crystalline, very hard, subconchoidal fracture in places, numerous cavities, unit grades to buff and slightly sandy in lower one half	1.2
26. Dolomite, buff to pinkish in parts, fine to coarse sandy, very poor sorting, dense, hard	0.5
Cambrian system (?)	
Trempealeau formation	
Madison sandstone member:	
25. Dolomite, very sandy to sandstone, very dolomitic, buff, grading to pinkish gray in center, sand medium- to fine-grained, poorly sorted, hard	1.5
24. Sandstone, buff, highly dolomitic with euhedral dolomite crystals, sand medium- to fine-grained, well-sorted	1.8
23. Dolomite, buff, sandy, finely crystalline, sand, fine- to coarse-grained, moderately to poorly sorted	1.6
Madison sandstone member:	
22. Sandstone and dolomite crystals in equal proportions, buff, sand medium- to coarse-grained, fairly well-sorted, hard	1.1

		Feet
21.	Sandstone, buff to brown, medium-grained, fairly well-sorted, calcite-cemented in part. Cross lamination and bedding planes weathered into relief where calcite cementation has been concentrated	5.5
20.	Sandstone, buff, fine-grained, well-sorted, unconsolidated, with numerous worm borings	0.7
19.	Sandstone, white, fine- to coarse-grained, poorly sorted, soft, unconsolidated, as one bed	0.7
18.	Sandstone, buff and white, fine-grained, well-sorted, in thin interbedded bands of massive uncemented sandstone and blocky calcite-cemented sandstone	5.0
17.	Sandstone, buff, light brown and white, fine-, medium- or coarse-grained, moderately to poorly sorted. Unit consists of closely spaced calcite-cemented ledges with seams of unconsolidated material between; traces of green shale 3 feet above base	6.0
	Jordan sandstone member:	
16.	Sandstone, brown, coarse-grained, well-sorted, subangular to curvilinear, unconsolidated, massive, grading to medium-grained between 30 and 35 feet and becoming ledgy between 50 and 55 feet	64.5
15.	Sandstone, light buff, fine- to medium-grained, very well-sorted, unconsolidated, massive	10.0
14.	Sandstone, light buff to white, fine- to medium-grained, very well-sorted	10.0
	(Section transferred to adjacent road cut north of ravine. No loss of beds.)	
13.	Sandstone, very light buff to white, fine-grained, very well-sorted, slightly cemented but friable at top, becoming more firm toward the base; worm borings abundant; as heavy massive beds	6.3
12.	Sandstone, an irregular pockety zone of coarse- to very coarse-grained, variably cemented sandstone and very fine-grained well-sorted sandstone	1.5
11.	Sandstone, light buff to white, fine- to medium-grained, unconsolidated but very thinly laminated with a hard band in the center; lower portion bears innumerable worm borings	0.8
10.	Sandstone, buff to white mottled, very fine-grained; as heavy massive beds	5.0
	Lodi siltstone member:	
9.	Sandstone, greenish buff, very fine-grained to siltstone, thinly interlaminated with thin green shale partings; weathers to thin flat irregular slabs giving a shaly appearance	5.0
8.	Sandstone, buff, extremely fine-grained to siltstone, dolomite-cemented, weathering to a prominent bed; numerous small cavities	1.0
7.	Sandstone, light buff, extremely fine-grained, well-sorted, soft in parts shaly; grading down into	0.5
6.	Sandstone, brown to purplish gray, highly irregular in structure, conglomeratic with light buff, thin, flat pebbles and stringers	0.5
5.	Concealed	4.5
4.	Siltstone to extremely fine-grained sandstone, brown to buff, very well-sorted and very homogeneous in character; breaks into flat dolomite-cemented slabs 1 inch to 3 inches thick	5.3
	St. Lawrence dolomite member:	
3.	Dolomite, bluish drab, fine to medium crystalline, moderately glauconitic, becoming highly so in upper 2 inches unit somewhat conglomeratic, hard, contains numerous small cavities	2.0
2.	Siltstone or very fine-grained sandstone, buff weathered, slightly glauconitic, slabby in upper 1½ foot becoming more massive below; green shale partings common in parts	6.8
1.	Sandstone, light buff, fine-grained, well-sorted, green-mottled with green shale partings; irregular fracture	1.0

Base of exposure is 763 feet above sea level.

Exposure 139

Location: West center SW¼SE¼ sec. 10 T. 95 N., R. 3 W. Exposure 0.57 of a mile north along road from bridge at Marquette, and 2.27 miles south along road from road crossing immediately south of bridge across Yellow River. Exposure it found in small sag carved by stream.

Ordovician system

Oneota formation

	Feet
17. Dolomite (extending upward in ravine bed)	10.
16. Dolomite, drab to pinkish and buff, finely crystalline, highly sandy; sand coarse- to fine-grained with stringers and pockets of coarse-grained sand	0.7
15. Sandstone, drab to buff, fine-grained, well-sorted, very highly dolomitic, very hard, dense, strong blocky fracture, cross-laminated, in well-defined beds 2 to 6 inches thick	2.7

Cambrian system

Trempealeau formation

Madison sandstone member:

14. Sandstone, buff, medium- to coarse-grained, fair sorting, strongly cemented, blocky fracture, thick-bedded	2.0
13. Sandstone, buff, coarse-grained, poorly sorted, conglomeratic, dolomite-cemented, hard, worm borings common, some cross-lamination	3.3
12. Sandstone, light buff, coarse-grained in upper 6 inches grading to medium-grained below, well-sorted, cross-laminated with streaks white sand parallel to cross lamination in top 6 to 8 inches	3.0
11. Sandstone, buff, fine- to coarse-grained, poorly sorted, somewhat dolomite-cemented; weathers thin-bedded	1.8
10. Sandstone, very light buff to light gray, coarse- to medium-grained, poorly sorted, massive; numerous green shale partings, unconsolidated	2.0
9. Sandstone, buff to pinkish, fine- to coarse-grained, poorly sorted, strongly dolomite cemented, blocky fracture, in beds 2 to 6 inches thick	2.0
8. Sandstone, white, medium- to very coarse-grained, poorly sorted, unconsolidated, massive; innumerable green shale partings	0.7
7. Sandstone, buff, fine- to very coarse-grained, very poorly sorted, conglomeratic, dolomite-cemented, green shale partings in parts, worm borings common	2.3
6. Sandstone, light buff, medium- to coarse-grained, fairly well-sorted, unconsolidated, massive, friable	1.0
5. Sandstone, light buff, fine- to medium-grained with sprinkling coarse grains, moderately to poorly sorted, dolomite-cemented, worm borings common in upper part	1.1
4. Sandstone, buff, coarse-grained, well-sorted, dolomitic but friable, highly conglomeratic	1.5
3. Sandstone, light buff, coarse-grained, well-sorted, unconsolidated, massive; with 2 thin green shale partings at 7 and 14 inches below top	2.0
2. Sandstone, buff, coarse-grained, well-sorted, with much interstitial crystalline dolomite, highly conglomeratic in upper part and thinly horizontally bedded in lower portion	1.3

Jordan sandstone member:

1. Sandstone, light buff, coarse-grained, well-sorted, unconsolidated, friable with occasional green shale flakes, massive	1.2

Base of section is 632 feet above sea level.

Lansing City Well No. 3

Location: Middle of intersection of Main and Front Streets, Lansing, Iowa.
Elevation: Curb of well is 639 feet above sea level.

	Feet
Pleistocene system	
River alluvium	
1. Sand, brown, coarse-grained to granules, many abraded dark brown rock fragments	133
Cambrian system	
Franconia formation	
Goodenough member	
2. Siltstone or shale (well mud), pale green, slightly micaceous	64
Ironton member (thickness selected arbitrarily)	
3. Sandstone, white, coarse-grained, well-sorted, clean	20±
Dresbach formation	
Galesville member	
4. Sandstone, white, coarse-grained, well-sorted, clean	57±
5. Sandstone, bluish white, coarse- to very coarse-grained, well-frosted and rounded	17
Eau Claire member	
6. Sandstone, white, very fine-grained, very well-sorted, slightly glauconitic, slightly micaceous	49
7. Siltstone to fine-grained sandstone, pale orange	9
8. Siltstone to fine-grained sandstone, orange	7
9. Sandstone, white, very fine-grained, very well-sorted, slightly glauconitic, slightly micaceous	16
10. Sandstone, white, coarse-grained, well-sorted, clean	9
11. Sandstone, white very fine-grained, very well-sorted, slightly glauconitic, slightly micaceous	44
Mt. Simon member	
12. Sandstone, light yellow, coarse-grained, well-sorted, clean	6
13. Sandstone, white, coarse-grained, well-sorted, clean	47
14. Sandstone, brown, coarse-grained, fair sorting, clay coated	10
15. Sandstone, light yellow, coarse-grained, well-sorted, clean	181
16. Sandstone, brown, coarse-grained, well-sorted, clay coated	8
17. Sandstone, white, coarse-grained, well-sorted, clean	15
18. Sandstone, brown, coarse-grained, fair sorting, clay coated	7
19. Sandstone, white, coarse-grained, well-sorted, clean	8
20. Sandstone, brown, coarse-grained, well-sorted, clay coated	8
21. Sandstone, very coarse-grained to granules, well-rounded, 99% quartz sand	38

Marquette

Chicago, Milwaukee, St. Paul and Pacific Railroad Well

Elevation: Curb of well is 628 feet above sea level.

Pleistocene system	
River alluvium	
1. Silt, buff, clayey, some sand, slightly calcareous	60
2. Clay, reddish gray, soft, unctuous, with considerable sand	10
3. Sand, buff, coarse medium-grained, clayey, with chert and limestone fragments in lower part	10
Cambrian system	
Franconia formation	
Goodenough (?) and Hudson members	
4. Sandstone, buff, very fine-grained, well-sorted, slightly cemented, silty; with 10-15 percent white chert in upper part	10

		Feet
5.	Concealed	10
6.	Dolomite, very light buff to light gray, finely crystalline, very sandy in parts, slightly glauconitic	40
7.	Dolomite, light buff, finely crystalline, translucent, hard, slightly glauconitic	35
8.	Sandstone to shale, light gray, very fine-grained, very silty, glauconitic	10
9.	Sandstone, greenish gray, silty to clayey, moderately glauconitic	15
10.	Sandstone to shale, light gray, very fine-grained, very silty, glauconitic	50
11.	No sample	10
12.	Sandstone to shale, light gray, very fine-grained, very silty, glauconitic	10
13.	No sample	15
	Ironton member	
14.	Sandstone, light buff, medium- to coarse-grained, dolomite-cemented in parts, glauconitic	15
15.	Sandstone, white, coarse- to medium-grained, curvilinear to subround, well-frosted, well-rounded, no glauconite	30
	Dresbach formation	
	Galesville member	
16.	Sandstone, white predominantly medium- to coarse-grained, well-sorted, very slightly cemented in upper 10 feet	90
	Eau Claire member (?)	
17.	Sandstone, medium-grained grading to fine, slightly dolomitic, slight traces of shale	20

Waukon City Well No. 3

Elevation: Curb of well is 1279 feet above sea level.

	Cambrian system	
	Trempealeau formation	
	Madison member (top 548 feet below curb)	
1.	Sandstone, light buff, fine- to coarse-grained, poorly sorted, subangular to curvilinear, well-frosted, slightly dolomitic in lower part	22
	Jordan member	
2.	Sandstone, light buff, medium- to coarse-grained, curvilinear to subround, clean	30
3.	No sample	20
4.	Sandstone, light buff, medium- to coarse-grained, clean	20
5.	Sandstone, light buff to white, medium- to fine-grained clean	20
6.	Sandstone, light buff, medium- to coarse-grained, clean	10
	Lodi member	
7.	Sandstone, very fine-grained to siltstone, white, uncemented	10
8.	Sandstone, medium- to fine-grained, predominantly medium	7
	St. Lawrence member	
9.	Dolomite, dark drab gray, medium crystalline, translucent, medium to coarse sandy	13
	Franconia formation	
10.	Sandstone, light gray, fine-grained, angular, well-sorted, slightly glauconitic	40
11.	Sandstone, light gray, fine-grained, strongly dolomite-cemented, grading in lower part to 50 percent light brown very finely crystalline dolomite. One thin band brown, translucent, fine to medium crystalline dolomite with large glauconite grains and medium- to coarse-grained sand	25
12.	Sandstone, very fine-grained, to siltstone, pale green, very clayey, uncemented	35
13.	No sample (Driller's log reports green clayey shale)	75
14.	Sandstone, very fine-grained, to siltstone, pale green, very clayey, uncemented	5

Ironton member (?)

15. Sandstone, medium- to coarse-grained, moderately to poorly sorted, subangular to curvilinear, moderately frosted, slightly dolomite-cemented, slightly glauconitic ... 20

Dresbach formation (?)

Galesville member (?)

16. Sandstone, white, medium- to fine-grained, well-sorted, uncemented, no glauconite ... 10

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MINERAL PRODUCTION IN IOWA FOR 1939 AND 1940

by

H. GARLAND HERSHEY

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MINERAL PRODUCTION IN IOWA FOR 1939 AND 1940

BY H. GARLAND HERSHEY

INTRODUCTION

In this report the Iowa Geological Survey presents a detailed record of developments and trends of the mineral industries in the State for the years 1939 and 1940. Statistical summaries of this type have been published periodically by the Survey for the past 45 years. Their primary function is to supply producers and consumers of mineral products, as well as the general public, with as much factual information as possible, chiefly in the form of tables. With the greatly increased interest in minerals and mineral production brought about by national defense and war activities, reports of this type have been useful in evaluating the role that Iowa can play in the total war effort.

All minerals produced in Iowa at the present time fall in the class of nonmetallics. The leading products are coal, cement, gypsum, limestone, clay and clay products, and sand and gravel. Of less importance are sandstone, peat, and woolrock. None of the minerals defined as strategic or critical to the war effort are produced in the State.

Lead, zinc, and iron have been mined profitably in Iowa in the past. The reserves are known to be small, but economic conditions resulting from the war may again make it practicable to bring these ores into production.

Iowa contains large quantities of dolomite which is relatively high in magnesium, a metal of importance in the national defense and war program because of its use in airplane motors and incendiary bombs. The source of magnesium produced in the United States until now has been from brine pumped from deep wells and from sea water. Plans were under way in late 1940 to utilize magnesite and brucite as ores. From this it appears possible that dolomite may become a source of raw material for magnesium production, although extraction is a costly and intricate process.

ACKNOWLEDGMENTS

Collection of the information which forms a basis of this report was carried on by the U. S. Bureau of Mines in cooperation with

TABLE 1

Summary of mineral production of Iowa, 1938-40

	1938		1939		1940	
	Quantity	Value	Quantity	Value	Quantity	Value
Cement (shipments)—bbls.	4,759,390	$7,327,048	4,717,295	$7,771,503	4,597,781	$7,641,163
Clay						
Products	....	2,868,233a	....	3,698,611a	....	3,649,000
Raw	6,828	45,759	5,615	50,939	10,005	51,267
Coal—tons	3,103,187b	7,963,000c	2,947,557d	7,189,245c	3,231,177d	8,060,587
Gypsum (e)—tons	364,920	495,856	430,712	510,120	487,379	587,223
Limestone—tons	3,369,750f	3,782,480f	6,400,590f	4,385,234f	4,013,740	3,832,070
Sand and gravel—tons	6,994,286g	2,299,682g	5,789,687	1,540,029	6,451,845	2,156,594
Miscellaneous	....	1,142,004	....	1,935,549	....	1,140,666
Total (h)	....	$24,794,058g	....	$25,170,181	....	$26,006,904

a. Figures obtained from Bureau of the Census.
b. According to the Bituminous Coal Commission (Revised).
c. Value is estimated from several sources and includes selling expense (Revised).
d. According to Bituminous Coal Division (Preliminary).
e. Crude mined.
f. Includes sandstone and miscellaneous stone, tonnage approximate.
g. Revised.
h. After eliminating duplications.

the State Survey except for the canvasses of clay products and coal. The data on clay products were furnished by the U. S. Bureau of the Census for 1939 and 1940 supplemented by material from the Bureau of Mines in 1940. Statistics on coal are based on data published by the National Bituminous Coal Commission and its successor the Bituminous Coal Division, U. S. Department of the Interior. Material published by the Bureau of Mines, particularly that from the Minerals Yearbooks, was drawn on freely for this review.

In addition to acknowledging the cooperation and assistance of the Federal agencies, it is a pleasure to express appreciation to the mineral producers in Iowa for furnishing their individual reports which make this summary possible. The writer also wishes to acknowledge the assistance of the staff of the Iowa Geological Survey in preparing this material for publication.

GENERAL STATEMENT

Total value of mineral production in Iowa for 1939 was $25,-170,181, an increase of 1.5 percent over the $24,794,058 of 1938. Production values of cement, clay, gypsum, and limestone increased in 1939 while those for coal and sand and gravel fell below 1938 levels. In 1940 the total value of mineral production advanced to $26,006,904, or 3.3 percent above 1939. The values of coal, gypsum, and sand and gravel were greater than the 1939 figures for those commodities although the values of cement, clay, and limestone declined (see table 1).

For more than 50 years coal had ranked first among the mineral products of Iowa in annual value of production, but in 1939 it dropped to second place by a small margin. In 1940, however, coal was again in first ranking position with cement second. Limestone ranked third in both years followed by clay and clay products, commercial sand and gravel, and gypsum. The true value of gypsum, however, is not apparent from the data available. Only the quantity and value of crude gypsum mined have been reported in the past few years. The unreported annual values of calcined gypsum are estimated to be such that they would place gypsum in third ranking position as a state mineral resource for the period covered by this report.

From a national viewpoint gypsum remained the most important Iowa mineral product, owing to the fact that this State is the third largest producer of crude gypsum in the nation. It is outranked only by New York and Michigan.

Detailed statistics for sandstone and peat are not published in order that confidential information will not be revealed. Data are not available on the production of the one rock wool plant operating in the State.

Trends in the mineral industries of Iowa did not follow the general tendencies of mineral production of the country as a whole. After a general decline in production values of mineral industries in the United States in 1938, almost all branches recovered after the first five months of 1939 and continued to advance through 1940 when the physical volume of production was greater than for any previous year in the history of the nation. In 1939 metals as a group advanced 44.7 percent in value, nonmetals other than fuels 21.2 percent and fuels 0.5 percent over 1938. Total value of mineral production in 1940 was 14.3 percent above 1939, for nonmetallics alone 8.6 percent. It was the highest total value since 1926 and more than double that of each of the depression years of 1932 and 1933. Table 2 outlines mineral production in the United States for the period of this report.

Mineral production did not advance as rapidly in 1939 as business in general. The Federal Reserve Board index of industrial production (1935-39 average = 100), accepted as a reliable business indicator, was 86 for industrial activity and 99 for minerals in 1938. In 1939 the figure for industrial activity rose to 106 while that for minerals increased only to 108.

In 1940 the average index for industrial activity advanced to a new high of 122. After a decline in the early months of 1940 it began to rise and by December it had reached 139. A precise index for mineral consumption is not available but it did not reach the record high of business in general. This was probably due to the low rate of building activity. The index of construction contract awards was 72 in 1939 and 81 in 1940 (value basis 1923-25 = 100).

TABLE 2

Value of mineral products of the United States, 1938-40

Year	Metallic	Nonmetallic			Grand Total
		Fuels (a)	Other	Total	
1938b	$ 892,600,000	$2,820,300,000	$650,300,000	$3,470,600,000	$4,363,200,000
1939b	1,291,700,000	2,834,300,000	788,200,000	3,622,500,000	4,914,200,000
1940b	1,679,500,000	3,116,500,000	818,800,000	3,935,300,000	5,614,800,000

a. Coal, natural gas, natural gasoline, petroleum.
b. All figures revised.

CEMENT

The value of shipments from the five active portland cement plants in Iowa amounted to $7,771,503 in 1939 (see table 3). This represented an increase of more than 6 percent over 1938 and was the highest value recorded since 1930. By virtue of this value, cement became the leading mineral product of Iowa for 1939. In 1940 it dropped to second ranking position when the value of shipments declined to $7,641,163. The value of cement shipped from the mills in Iowa represented 30.5 percent of the total mineral production of the State in 1939 and 29.4 percent in 1940.

Volume of shipments in 1939 was 0.9 percent below the 1938 level and in 1940 showed a 2.5-percent decline from 1939. The apparent discrepancy between the figures for value and volume of shipments is readily explained by price. The average price per barrel (376 lbs.) advanced from $1.54 in 1938 to $1.65 in 1939 and in 1940 to $1.66, higher than the mill price in any other state.

Production of cement decreased from 4,762,517 barrels in 1938 to 4,718,024 barrels in 1939, a drop of 0.9 percent, and in 1940 decreased 2.4 percent below the 1939 level to 4,605,886 barrels. As a consequence the amount of electrical energy used by the industry was reduced in 1940, although the amount purchased increased 36 percent.

Iowa produces more cement than is used within the State. Apparent consumption (shipments plus imports minus exports) amounted to 2,994,325 barrels in 1939 and 2,933,570 barrels in 1940. Comparing these figures with those for total production in table 3 it is seen that the apparent exports amounted to about 36 percent of total production for both years. These figures indicate that the per capita consumption of cement in Iowa was 1.17 barrels in 1939 and 1.16 barrels in 1940, which ranked this State the seventh and eighth largest cement consumer on the per capita basis in the respective years.

TABLE 3

Salient features of the cement industry in Iowa, 1938-40

	1938	1939	1940a
Production, bbls.	4,726,517	4,718,024	4,605,886
Shipments, bbls.	4,759,390	4,717,295	4,597,781
Shipments, value	$ 7,327,048	$ 7,771,503	$ 7,641,163
Average factory value per bbl.	$1.54	$1.65	$1.66
Stock, Dec. 31, end of year	1,541,951b	1,542,680	1,550,802
Annual capacity		9,455,710	9,411,534
Electrical energy generated		97,754,900c	89,926,500c
Electrical energy purchased		9,057,272c	12,343,603c
Electrical energy used		106,812,172c	102,270,103c
Number of producers	5d	5d	5d

a. Subject to revision.
b. Revised.
c. Kilowatt hours.
d. One plant idle.

Iowa ranked seventh among the cement producing states on the basis of value of shipments. However, production of cement in Iowa has not followed the trends of the industry as a whole. This was particularly striking in 1939 when all leading states except Iowa showed increases over 1938 averaging 16 and 15 percent in quantity and shipments respectively. In 1940 Iowa was one of the two states in which the production and shipments of cement did not increase. The average factory value per barrel for the United States was $1.47 in 1939 and $1.46 in 1940, or 18 and 20 cents per barrel lower than the Iowa averages for those years. A summary of cement production in the United States is shown in table 4.

Varied demands of construction during recent years have led to the development of several distinct types of portland cements adaptable to specialized uses. These include high-early-strength, masonry, low-heat and oil-well cements. United States shipments in 1939 included 3,693,460 barrels of high-early-strength cement valued at $6,964,608 (average price $1.89 a barrel). In 1940 shipments of the same type amounted to 4,401,274 barrels valued at $8,241,879 or an average price of $1.87 a barrel. In 1939 natural, masonry (natural), and puzzolan cements advanced as a group 29 percent in quantity and 23 percent in value of shipments over 1938. They advanced 5 percent in quantity and 0.7 percent in value of shipments in 1940.

TABLE 4.

Statistics on the portland cement industry in the United States, 1938-40

	1938	1939	1940a
Production, bbls.	105,357,000	122,259,154	130,216,511
Shipments, bbls.	106,324,127	125,056,594	132,864,383
Shipments, value	$153,977,226	$184,254,932	$193,464,869
Average factory value per bbl.	$1.45	$1.47	$1.46
Stocks, (b) Dec. 31, end of year	23,992,939c	23,645,583c	23,364,657
Number of producers	151	150	152

a. Subject to revision.
b. Stock at mills.
c. Revised.

CLAY

The value of sales of clay and clay products in Iowa amounted to $3,749,550 in 1939, an increase of 29 percent over the recession year of 1938 (see table 5). In 1940 the value declined slightly to $3,700,267.

The chief value of the clays (including shales) in Iowa is their use for making clay products. This branch of the industry normally accounts for approximately 98 percent of the total production. Unglazed structural tile, drain and sewer tile, and red and buff burning building brick are the leading products although numerous other types of brick and tile are made. Clay products have shown a steady increase in production values since 1932 except for 1938, and the value in 1939 was higher than in any other year since 1930. The value for 1940 was second to 1939 for the 1930-1940 period and was more than four times the value of production for 1932 and for 1933.

In 1939 the value of structural tile sold was $1,088,553 as compared with $1,157,948 in 1938 and $1,225,425 in 1940. The combined value of drain tile and sewer tile was over 1 million dollars in 1939 and almost 1.5 million dollars in 1940. Total value of all types of building brick advanced from $648,356 in 1938 to $937,416 in 1939 but dropped to $767,472 in 1940.

TABLE 5

Value of clay products and raw clay in Iowa, 1938-40

	1938	1939	1940
Clay products	$ 2,868,233	$ 3,698,611	$ 3,649,000
Clay, raw	45,759	50,939	51,267
Total	$ 2,913,992	$ 3,749,550	$ 3,700,267

Sales of raw and prepared clays and shales in Iowa recovered in 1939 from the slight decline in 1938, and advanced again in 1940 (see table 6). The increase amounted to 11.3 percent in value in 1939 and about 0.6 percent in 1940. In 1939 sales of both fire clay and miscellaneous clays increased. In 1940, however, sales of fire clay dropped but the increase in the sales of miscellaneous clays was sufficient to bring the total to the highest value since 1930. Shale used for mortar mix is the leading product in the category of miscellaneous clays.

TABLE 6

Sales of clay in Iowa, 1938-40

	1938	1939	1940
Fire Clay			
Short tons	773	960	(b)
Value	$ 9,034	$ 10,858	(b)
Active producers	3	3	(b)
Miscellaneous Clay (a)			
Short tons	6,828	5,615	10,005
Value	$ 36,725	$ 40,081	$ 51,267
Active producers	8	7	10
Total Clay			
Short tons	6,828	5,615	10,005
Value	$ 45,759	$ 50,939	$ 51,267
Active producers	10	10	10

a. Chiefly mortar mix.
b. Small amount of fire clay included in miscellaneous for concealment purposes.

The salient features of the potteries industry in the United States for 1939 were the new high records attained by the sales of domestic china and paper clay, ball clay and bentonite; the decline in the consumption of natural bleaching clays or fuller's earth; the partial recovery of fire clay sales; and the slight advance in the tonnage of miscellaneous clay sold. In 1940 shipments of china clay, ball clay, and bentonite increased notably over the highs attained in 1939. Shipments of fire clay rose sharply but consumption of natural bleaching clays fell below expectations.

COAL

The Iowa coal mining industry suffered a decline in 1939 when the production was 2,947,557 tons (see table 7) valued at $7,189,245 as compared to the output of 3,103,187 tons valued at $7,963,000 in 1938. Production recovered in 1940 to 3,231,177 tons with a value of $8,060,587. These figures indicate a decrease in production of 5.0 percent in 1939 and an increase of 9.6 percent in 1940. Records of coal production for the United States as a whole show an increase in output over the preceding year of 13 percent in 1939 and 17 percent in 1940.

Variations in the annual production of coal in Iowa did not have a proportional effect on the employment of workmen as shown by table 8. Fewer men were employed in each successive year from 1937 to 1939. In 1940, when production increased 9.6 percent the number of men employed decreased 0.5 percent although the man-shifts of labor increased 7.1 percent.

Detailed statistics for coal for 1938 were not available when data on other mineral commodities were published for that year. Records for 1938 are therefore included in this report. All data on coal include only those mines producing 1000 tons or more a year.

Details of the coal mining industry in Iowa by counties are presented in tables 9 to 11. They show that Marion County was the leading producer in each of the years covered by this report. The leading coal-producing counties are listed below in order of rank by years.

1938	1939	1940
Marion	Marion	Marion
Lucas	Dallas	Appanoose
Appanoose	Appanoose	Polk
Boone	Polk	Mahaska
Dallas	Mahaska	Dallas
Polk	Boone	Boone

TABLE 7

Estimated monthly production of coal in Iowa, 1938-40 in thousands of net tons

Month	1938	1939	1940
January	368	323	422
February	294	316	328
March	270	321	256
April	197	259	203
May	193	114	200
June	181	116	189
July	160	151	193
August	202	208	230
September	250	244	272
October	298	309	261
November	342	285	324
December	348	302	353
Total	3103	2948	3231

Most of the coal recovered in Iowa is from underground mines, but an increasingly larger proportion has been obtained from strip pits in the past few years (see table 12). Of the total output from underground a very large proportion is either shot off the solid or cut by machines, very little is mined by hand. In 1938 there were 104 coal-cutting machines in use in the State, 3 of which were track mounted. The average output of these machines was 10,569 net tons. In 1939 an average production of 9,093 tons was obtained from 103 cutting machines 6 of which were track mounted and in 1940 an average of 10,863 tons was cut by 93 machines.

In recent years there has been a decided increase in the use of power drills for shot-hole drilling. In 1936 in the area including Iowa, Kansas and Missouri, operations where shot holes were power drilled produced 80,000 tons of coal. In 1938 production from mines of this type in the same area had increased to 164,084 tons. By 1940 in Iowa alone total production from mines using power drills was 334,268 tons. All drills in Iowa were electrically driven.

Mechanical loading of coal underground has increased in Iowa. In 1939 a total of 66,422 tons were produced from three mines using 6 hand-loaded conveyors. A production of 132,947 tons was obtained from 11 conveyors in 4 Iowa mines in 1940.

TABLE 8

Number of mines, production, men employed, days operated, man-days of labor, and output per man per day in Iowa, 1937-40

	1937	1938	1939	1940
Number of active mines	340	261	271	276
Loaded at mines for shipment by rail, net tons	1,731,173	1,642,445	1,408,854	1,424,398
Shipped by truck or wagon, net tons	1,833,005	1,412,311	1,478,839	1,755,138
Coal used by employees or taken by locomotives at tipple or other uses at mines, net tons	45,237	31,853	43,383	37,736
Used for power and heat, net tons	25,922	16,578	11,649	13,905
Total production, net tons	3,637,054	3,103,187	2,947,557a	3,231,177
Average value per ton	....	$2.57	$2.44	$2.49
Number of employees:				
Underground	(b)	6,234	5,220	5,061
Surface				
In strip pits	(b)	322	322	370
All others	(b)	816	709	790
Total	8,720	7,372	6,251	6,221
Average number of days mine operated	146	136	147	158
Man-days of labor	1,267,270c	1,000,795	920,226	985,478
Average tons per man per day	2.87	3.10	3.20	3.28

a. Includes increase of 4,832 tons to stock of coal at mines.
b. Not available.
c. Calculated.

TABLE 9

Production of coal, men employed, days operated and output per man per day by counties in Iowa, 1938

County	Net Tons					Number of employees				Average number of days mines operated	Man-days of labor	Average tons per man per day
	Loaded at mines for shipment by rail	Shipped by truck or wagon	Coal used by employees or taken by locomotives at tipple or other uses at mines	Used for power and heat	Total quantity	Underground	Surface: In strip pits	Surface: All others	Total			
Adams	....	21,341	100	105	21,546	117	......	10	127	146	18,579	1.16
Appanoose	284,829	106,606	1,985	83	393,503	1,403	......	190	1,593	113	179,447	2.19
Boone	289,930	77,843	5,663	2,082	375,518	773	......	89	862	162	139,695	2.69
Dallas	280,350	78,352	6,130	1,302	366,134	613	......	48	661	152	100,220	3.65
Davi and Taylor	202	24,027	529	16	24,774	39	14	5	58	158	9,158	2.71
Greene	....	19,001	....	5	19,006	48	15	5	68	68	4,612	4.12
Guthrie	....	18,462	118	25	18,605	79	......	8	87	161	13,998	1.33
Jasper	....	27,841	486	262	28,589	93	......	12	105	72	7,581	3.77
Jefferson and Keokuk	....	12,692	203	51	12,946	21	11	6	38	117	4,462	2.90
Lucas	415,432	13,369	4,893	2,135	435,829	672	......	63	735	148	108,819	4.01
Mahaska	91,466	111,043	2,908	1,391	206,808	81	107	39	227	173	39,380	5.25
Marion	112,468	326,871	2,375	1,264	442,978	659	107	121	887	130	114,884	3.86
Monroe	75,169	59,446	2,693	1,292	138,600	289	3	41	333	133	44,276	3.13
Page	....	32,247	225	15	32,487	94	......	13	107	186	19,896	1.63
Polk	62,128	223,043	2,781	2,048	290,000	738	......	68	806	124	99,889	2.90
Van Buren	64	18,613	223	35	18,935	28	13	9	50	170	8,521	2.22
Wapello	30,407	116,358	160	1,992	148,917	190	12	5	237	161	38,186	3.90
Warr.n	....	79 132	40	2,422	81,594	171	23	35	229	105	23,963	3.40
Wayne	....	18,426	310	....	18,736	82	......	10	92	154	14,177	1.32
Webster	....	27,598	31	53	27,682	44	17	9	70	158	11,052	2.50
Total Iowa, 1938	1,642,445	1,412,311	31,853	16,578	3,103,187	6,234	322	816	7,372	136	1,000,795	3.10
Total Iowa, 1937	1,731,173	1,833,005	45,237	25,922	3,637,054	8,720	......	......	......	146	....	2.87

TABLE 10

Production, value, employment, days active, and output per man-shift at bituminous coal mines in Iowa in 1939 by counties

County	Disposition of coal produced (net tons)						Average value per ton (c)	Average number of employees				Average number of full days mines were active	Tons of coal produced on active days per man-shift
	Loaded for shipment by rail (a)	Shipped by truck or wagon (excluding coal used by mine employees)	Used by mine employees, taken by locomotive tenders at tipple, or other uses at mines (b)	Used at mine for power and heat	Net changes in stocks of coal at mines Jan. 1, 1939 to Jan. 1, 1940	Total quantity		Underground	Surface: In strip pits	Surface: All others	Total		
Adams	....	17,493	60	8	....	17,561	$2.63	78	......	12	90	136	1.44
Appanoose	207,041	134,656	2,745	309	—696	344,055	2.49	1,197	......	141	1,338	118	2.19
Boone	169,233	63,325	14,796	1,433	—179	248,608	3.00	540	......	66	606	149	2.76
Dallas	319,238	62,363	6,883	1,273	—120	389,637	2.69	596	......	43	639	196	3.12
Greene	....	20,554	124	130	....	20,808	2.69	43	11	12	66	87	3.61
Guthrie	....	24,185	15	....	+138	24,338	2.99	98	......	10	108	153	1.47
Jasper	....	26,699	740	114	+239	27,792	2.70	68	6	15	89	84	3.72
Mahaska	122 147	143,045	1,810	1,151	+2,628	270,781	2.04	87	135	63	285	163	5.84
Marion	158,762	365,913	3,921	1,556	—466	529,686	2.11	536	95	92	723	183	4.01
M nroe	53,480	47,706	1,571	944	—89	103,612	2.12	256	7	38	301	111	3.11
Page	....	35,230	381	....	....	35,611	2.73	88	......	10	98	177	2.05
Polk	74,031	228,158	3,877	1,350	+1,504	308,920	2.71	654	5	56	715	137	3.15
Van Buren	....	18,114	224	17	....	18,355	2.63	26	7	6	39	189	2.49
Wapello	53,118	123,111	907	834	+2,960	180,930	2.14	25	24	54	336	140	3.84
Warren	3,753	61,266	1,181	1,882	—1,067	67,015	2.60	112	21	27	160	108	3.88
Wayne	....	24,028	202	....	....	24,230	2.31	89	......	13	102	168	1.41
Webster	....	35,979	100	....	....	36,079	2.73	59	5	9	73	147	3.35
Other counties (Davis, Jefferson, Lucas, and Taylor)	248,051	47,014	3,846	648	—20	299,539	2.33	435	6	42	483	163	3.80
Total quantity, 1939	1,408,854	1,478,839	43,383	11,649	+4,832	2,947,557	2.44	5,220	322	709	6,251	147	3.20
Total quantity, 1938	1,642,445	1,412,331	31,853	16,578	....	3,103,187	2.57	6,234	322	816	7,372	136	3.10

a. Includes coal loaded at mine directly into railroad cars and hauled by truck to railroad siding for shipment by rail.
b. Includes coal transported from mines to points of use by conveyor, chute, or aerial tramway.
c. Value of all coal produced, f.o.b. mine, excluding selling cost.

TABLE 11

Production, value, employment, days active, and output per man-shift at bituminous coal mines in Iowa in 1940 by counties

County	Disposition of coal produced (net tons)					Average value per ton (c)	Average number of employees				Average number of full days mines were active	Number of man-days worked	Average tons per man per day
	Loaded for shipment by rail (a)	Shipped by truck or wagon (excluding coal used by mine employees)	Used by mine employees, taken by locomotive tenders at tipple, or other uses at mines (b)	Used at mine for power and heat	Total quantity		Underground	Surface		Total			
								In strip pits	All others				
Adams	....	19,148	30	82	19,260	$3.29	105	......	15	120	150	17,950	1.07
Appanoose	240,854	181,762	4,134	252	427,002	2.49	1,223	......	154	1,382	132	182,755	2.34
Boone	216,690	83,709	6,286	2,159	308,844	3.05	540	......	49	589	195	114,759	2.69
Dallas	256,692	85,094	6,268	1,305	349,359	2.64	661	......	41	702	159	111,912	3.12
Greene	....	19,235	259	537	20,031	3.09	39	7	5	51	109	5,550	3.61
Guthrie	....	25,376	215	15	25,606	3.68	137	......	14	151	140	21,143	1.21
Jasper	....	46,050	778	150	46,978	2.71	60	12	20	92	149	13,733	3.42
Lucas	167,062	23,197	2,970	1,219	194,448	2.22	256	......	24	280	165	46,305	4.20
Mahaska	179,533	171,117	1,362	1,617	353,629	2.05	67	159	78	304	170	51,773	6.83
Marion	131,351	403,535	3,252	235	538,373	2.08	481	97	112	690	173	119,638	4.50
Monroe	87,015	104,204	1,349	1,534	194,102	2.63	267	6	54	327	171	55,796	3.48
Page	....	40,136	433	30	40,599	2.98	129	......	19	148	143	21,230	1.91
Polk	88,285	261,310	8,135	1,610	359,340	2.89	585	5	64	654	179	117,065	3.07
Van Buren	....	23,699	140	87	23,926	2.70	23	19	13	55	149	8,176	2.93
Wapello	53,983	121,011	1,000	1,098	177,092	2.02	172	29	54	255	166	42,373	4.18
Warren	2,731	72,705	911	1,952	78,299	2.92	105	15	38	158	116	18,292	4.28
Wayne	....	24,295	99	....	24,394	2.32	98	......	14	112	132	14,805	1.65
Webster	....	22,818	55	5	22,878	2.77	58	4	13	75	119	8,920	2.56
Other counties (Davis, Jefferson, Keokuk, and Taylor)	202	26,737	60	18	27,017	2.77	50	17	9	76	175	13,303	2.03
Total quantity, 1940	1,424,398	1,755,138	37,736	13,905	3,231,177	2.49	5,061	370	790	6,221	158	985,478	3.28
Total quantity, 1939	1,408,854	1,478,839	43,383	11,649	2,947,557	2.44	5,220	322	709	6,251	147	920,226	3.20

a. Includes coal loaded at mine directly into railroad cars and hauled by truck to railroad siding for shipment by rail.
b. Includes coal transported from mines to points of use by conveyor, chute, or aerial tramway.
c. Value received or charged for coal f.o.b. mine, including selling cost. (Includes a value for coal not sold but used by producer, such as mine fuel and coal coked (not coke) as estimated by producer at average prices that might have been received if such coal had been sold commercially.)

TABLE 12

Bituminous coal mined by different methods in Iowa, 1938-40

	1938	1939	1940
From underground workings			
Mined by hand			
Net tons	341,061	450,186	282,315
Percent of total underground	12.9	19.0	11.3
Shot off the solid			
Net tons	1,182,356	975,117	1,212,723
Percent of total underground	44.8	41.3	48.4
Cut by machines			
Net tons	1,099,182	936,578	1,010,227
Percent of total underground	41.7	39.7	40.3
Not specified			
Net tons	14,733	0	0
Percent of total underground	0.6	0	0
Total underground			
Net tons	2,637,332	2,361,881	2,505,265
Percent of total underground	100.	100.	100.
From strip pits			
Net tons	465,855	585,676	725,912
Percent of grand total	15.0	19.9	22.5
Grand total production (net tons)	**3,103,187**	**2,947,557**	**3,231,177**

Stripping operations, begun on a large scale in 1932, increased steadily during the period of this report. Each year after 1937 established a new record high production from operations of this type (see table 12). Some of the salient features of stripping operations in the State for the period of this report are shown in table 13.

Reports are available on some of the truck mines in the State producing less than 1000 tons a year. Complete coverage was not possible. In 1938 a total production of 79,212 tons was obtained from 176 mines averaging 90 days of operation. These mines employed 745 men who put in 66,731 man-days of labor at an average output of 1.19 tons per man per day. These figures are not included in any other part of this report.

The output of soft coal in the United States was 394,855,325 tons in 1939 an increase of 13.3 percent over the 348,544,764 tons for 1938. Production increased 16.7 percent in 1940 to 460,771,500 tons (see table 14). Although the estimated average value per ton decreased 5.7 percent from $1.955 in 1938 to $1.850 in 1939, the calculated total value of production at mines increased 6.9 percent. An increase in average value to $1.913 in 1940 along with the increased production resulted in a gain of 20.7 percent in value over 1939.

During the first quarter of 1939 production was high because many consumers required excess storage to carry them over the

TABLE 13
Stripping operations in coal fields in Iowa, 1938-40 by counties

County	Number of strip pits	Number of power shovels: Steam	Number of power shovels: Electric	Number of power shovels: All others	Coal produced (net tons): Mined by stripping	Coal produced (net tons): Total at same mines	Number of employees: Underground	Number of employees: Surface, In strip pits	Number of employees: Surface, All others	Number of employees: Total	Average number of days mines operated	Percent of county total mined by stripping	Man-days of labor	Average tons per man per day
1938:														
Davis, Greene, Keokuk, Monroe Wapello, and Warren	7	......	2	6	88,042	88,042	......	78	18	96	110	21.5	10,558	8.34
Mahaska	10	......	......	11	172,364	172,364	......	107	25	132	182	83.3	24,063	7.16
Marion	11	......	......	15	190,360	190,360	......	107	29	136	197	43.0	26,750	7.12
Van Buren	3	......	......	2	10,384	10,384	......	13	3	16	200	54.8	3,200	3.25
Webster	3	......	......	4	4,705	4,705	......	17	2	19	66	17.0	1,258	3.74
Total, 1938	34	......	2	38	465,855	465,855	......	322	77	399	165	42.1a	65,829	7.08
1939:														
Davis, Greene, Jasper, Monroe, Polk, Van Buren, Warren, and Webster	11	1	2	6	70,331	70,331	......	68	28	96	130	......	12,510	5.62
Mahaska	11	2	1	16	227,874	227,874	......	135	49	184	162	84.2	29,744	7.66
Marion	9	......	......	18	215,023	215,023	......	95	19	114	215	40.6	24,496	8.78
Wapello	3	......	......	7	72,448	72,448	......	24	12	36	198	40.0	7,134	10.16
Total, 1939	34	3	3	47	585,676	585,676	......	322	108	430	172	......	73,884	7.93
1940:														
Davis, Greene, Jasper, Monroe, Polk, Van Buren, Warren, and Webster	14	......	2	13	79,008	79,008	......	85	41	126	104	......	13,139	6.01
Mahaska	13	......	2	19	315,159	315,159	......	159	63	222	180	89.1	39,870	7.90
Marion	13	......	......	21	252,095	252,095	......	97	39	136	228	46.8	30,976	8.14
Wapello	4	......	......	8	79,650	79,650	......	29	21	50	192	45.0	9,612	8.29
Total, 1940	44	......	4	61	725,912	725,912	......	370	164	534	175	......	93,597	7.76

a. Percent of county totals, not state.

anticipated suspension of mining on March 31 when the wage contract expired. Production declined sharply during April and May when mining was greatly curtailed pending the signing of a new wage contract. Output increased materially in the last quarter when general business picked up as a result of the outbreak of war in Europe and in 1940 exports increased 42 percent over 1939.

TABLE 14

Summary of bituminous-coal industry in the United States, 1938-40

	Production	Value at mines (calculated)	Average value per ton (a)	Stocks (b)		Consumption (c) (calculated)
				January 1	December 31	
1938	348,544,764	$681,405,014	$ 1.955d	47,074,000	40,720,000	344,649,800
1939	394,855,325	728,348,366e	1.850	40,720,000	44,571,000	379,768,962
1940	460,771,500	879,327,227e	1.913	44,571,000	50,998,000	438,250,143

a. F.O.B. mine, excluding selling expense except as noted.
b. Commercial consumers and retail yards.
c. Production plus imports minus exports plus or minus changes in consumers stock.
d. Average gross realization including selling expense.
e. Includes selling expenses.

An important event in the coal-mining industry was the establishment in 1940 of the minimum prices of bituminous coal f. o. b. mine by the Bituminous Coal Division to become effective October 1, 1940. This was made possible by the Coal Act of 1937 which was due to expire in April 1941, but which was extended 2 years by the Congress.

In recent years there has been a definite trend toward more complete mechanization by bituminous coal producers. In 1939 and 1940 there was a sharp increase in mechanical loading of coal in the United States and there were indications that the proportion of coal mechanically cleaned also increased substantially.

Tables 15, 16 and 17 present a summary of the production and employment features of the bituminous coal industry in the United States from 1938 to 1940.

GYPSUM

Iowa maintained the rank of third largest gypsum-producing state in the union by virtue of yielding 430,712 tons of crude gypsum valued at $510,120 from 9 mines in 1939 and 487,379 short

TABLE 15

Production, men employed, days operated, man-days of labor, and output per man per day at coal mines in the United States in 1938, by states

	Total quantity net tons	Number of employees				Average number of days mines operated	Man days of labor	Average tons per man per day
		Under ground	Surface		Total			
			In strip pits	All others				
Alabama	11,061,493	18,339	91	2,680	21,110	180	3,795,822	2.91
Alaska	154,682	100	....	44	144	204	29,413	5.26
Arizona, Georgia, Idaho, and Oregon	34,043	82	....	17	99	122	12,059	2.82
Arkansas	1,197,047	3,215	65	541	3,821	112	429,619	2.79
Colorado	5,663,144	6,897	10	1,378	8,285	169	1,400,088	4.04
Illinois	41,912,085	29,217	1,698	7,448	38,363	149	5,704,535	7.35
Indiana	14,758,484	6,244	1,935	2,350	10,529	149	1,570,984	9.40
Iowa	3,103,187	6,234	322	816	7,372	136	1,000,795	3.10
Kansas	2,654,141	1,861	680	545	3,086	170	525,115	5.05
Kentucky	38,545,218	45,096	60	7,007	52,163	160	8,351,492	4.62
Maryland	1,281,413	2,083	....	288	2,371	171	405,209	3.16
Michigan	494,481	1,099	....	106	1,205	163	195,825	2.53
Missouri	3,436,118	3,677	750	786	5,213	151	787,220	4.36
Montana (a)	2,732,050	1,126	40	359	1,525	174	265,784	10.28
New Mexico	1,239,037	1,968	....	506	2,474	153	378,011	3.28
North Dakota (a)	2,050,099	667	344	359	1,370	174	237,751	8.62
Ohio	18,590,618	23,306	920	3,167	27,393	145	3,984,353	4.67
Oklahoma	1,244,732	1,756	200	373	2,329	139	323,471	3.85
Pennsylvania	77,704,537	99,067	613	13,819	113,499	156	17,679,250	4.40
South Dakota (a)	48,058	18	23	9	50	170	8,507	5.65
Tennessee	4,472,403	7,094	4	1,168	8,266	167	1,383,487	3.23
Texas (a)	878,685	645	22	109	776	[illegible]	151,050	5.82
Utah	2,946,951	2,338	....	738	3,076	156	479,733	6.14
Virginia	12,283,036	14,559	....	2,202	16,761	174	2,918,100	4.21
Washington	1,566,973	1,990	....	601	2,591	163	423,119	3.70
West Virginia	93,288,172	87,852	56	15,131	103,039	175	18,082,703	5.16
Wyoming	5,203,877	3,474	44	905	4,423	181	801,879	6.49
Total quantity, 1938	348,544,764	370,004	7,877	63,452	441,333	162	71,325,374	4.89
Total quantity, 1937	445,531,449	....	....	....	491,864	193	....	4.69

a. Includes figures on lignite compiled by L. Mann, Bureau of Mines.

TABLE 16

Production, men employed, days operated, man-days of labor, and output per man per day at coal mines in the United States in 1939, by states

	Total quantity net tons	Average value per ton (a)	Number of employees: Under-ground	Number of employees: Surface: In strip pits	Number of employees: Surface: All others	Number of employees: Total	Average number of days mines operated	Man days of labor	Average tons per man per day
Alabama	12,046,675	$2.30	17,943	90	2,851	20,884	183	3,961,624	3.16
Arkansas	1,152,038	3.17	3,362	45	597	4,004	107	445,592	2.70
Colorado	5,923,210	2.47	6,782	....	....	8,161	176	1,526,292	4.12
Illinois	46,782,691	1.64	27,198	1,761	6,935	35,894	163	6,289,257	7.98
Indiana	16,942,772	1.48	5,338	2,140	2,288	9,766	177	1,856,838	9.79
Iowa	2,947,557	2.44	5,220	322	709	6,251	147	940,568	3.20
Kansas	2,674,691	1.89	1,772	525	561	2,858	178	530,905	5.25
Kentucky	42,556,568	1.74	43,881	93	6,667	50,641	180	9,375,987	4.68
Maryland	1,442,728	2.04	2,057	....	294	2,351	178	430,949	3.44
Michigan	456,754	3.77	1,038	....	116	1,154	155	188,396	2.55
Missouri	3,273,550	1.88	3,135	672	686	4,493	158	726,644	4.60
Montana	2,756,036	1.46	1,034	....	....	1,383	168	248,413	11.87
New Mexico	1,230,060	2.85	1,799	....	400	2,199	166	384,551	3.37
Ohio	20,289,553	1.63	17,657	1,050	2,935	21,642	175	3,898,899	5.35
Oklahoma	1,187,562	2.11	1,510	144	378	2,032	133	285,001	4.39
Pennsylvania	92,584,113	2.03	96,732	1,219	12,395	110,346	176	20,079,080	4.77
Tennessee	5,185,481	1.95	6,777	....	....	7,925	178	1,459,603	3.68
Utah	3,284,904	2.14	1,861	....	....	2,544	171	501,773	7.53
Virginia	13,530,974	1.85	13,814	....	1,811	15,625	186	3,021,200	4.66
Washington	1,690,442	3.11	1,755	....	....	2,275	191	450,202	3.90
West Virginia	108,361,934	1.76	88,410	289	14,554	103,233	190	20,280,013	5.51
Wyoming	5,373,289	2.00	2,947	53	757	3,757	207	811,855	6.92
Arizona, Georgia, Idaho, Oregon, and Texas	55,280	2.96b	297	....	96	393	88	36,309	1.59
Total quantity, 1939	394,855,325c	$1.850	353,476c	8,791c	59,521c	421,788c	178c	77,729,951	5.25c
Total quantity, 1938	348,544,764	....	370,004	7,877	63,452	441,333	162	71,325,374	4.89

a. Value of all coal produced, f.o.b. mine, excluding selling cost.
b. Texas (value $1.12 per ton) not included.
c. Includes lignite in Montana, North Dakota, South Dakota and Texas.

TABLE 17

Production, men employed, days operated, man-days of labor, and output per man per day at coal mines in the United States in 1940, by states

	Total quantity net tons	Average value per ton (a)	Number of employees: Underground	Number of employees: Surface: In strip pits	Number of employees: Surface: All others	Number of employees: Total	Average number of days mines operated	Man days of labor	Average tons per man per day
Alabama	15,324,163	$2.33	20,068	94	3,314	23,476	219	5,136,191	2.98
Alaska	173,844	3.49	70	....	28	98	322	31,541	5.51
Arizona, Idaho, and Oregon	16,902	3.32	37	....	9	46	210	9,663	1.75
Arkansas	1,453,611	3.36	3,194	58	623	3,875	136	527,621	2.76
Colorado	6,588,742	2.53	6,463	23	1,350	7,836	188	1,473,647	4.47
Georgia	42,307	2.38	96	....	34	130	217	28,248	1.50
Illinois	50,610,430	1.69	27,067	1,729	7,362	36,158	169	6,119,358	8.27
Indiana	18,868,572	1.53	5,085	1,751	2,819	9,655	188	1,815,165	10.39
Iowa	3,231,177	2.49	5,061	370	790	6,221	158	985,478	3.28
Kansas	3,578,952	1.88	1,601	474	739	2,814	196	550,869	6.50
Kentucky	49,140,904	1.85	47,442	100	7,254	54,796	200	10,986,433	4.47
Maryland	1,503,433	2.11	2,054	....	285	2,339	182	424,936	3.54
Michigan	410,169	3.88	773	....	97	870	187	163,091	2.51
Missouri	3,096,741	2.04	2,920	618	684	4,222	170	718,755	4.31
Montana (b)	2,867,200	1.45c	995	56	360	1,411	188	264,911	10.82
New Mexico	1,110,615	2.97	1,562	....	396	1,958	168	328,416	3.38
North Dakota (lignite)	2,218,434	1.17c	654	371	352	1,377	182	251,216	8.83
Ohio	22,771,552	1.71	16,893	1,227	3,054	21,174	193	4,076,578	5.59
Oklahoma	1,645,981	2.44	1,471	183	394	2,048	176	359,675	4.58
Pennsylvania	116,602,999	2.04	102,996	1,685	13,739	118,420	212	25,115,380	4.64
South Dakota (lignite)	66,085	1.33c	12	39	12	63	168	10,577	6.25
Tennessee	6,008,456	2.00	7,413	3	1,150	8,566	208	1,779,057	3.38
Texas (b)	620,555	1.10c	543	16	68	627	160	100,618	6.17
Utah	3,575,586	2.20	1,882	....	708	2,590	182	471,606	7.58
Virginia	15,348,075	1.95	14,793	5	2,222	17,020	199	3,391,223	4.53
Washington	1,650,352	3.16	1,838	5	482	2,325	188	436,530	3.78
West Virginia	126,437,621	1.83	88,684	127	15,924	104,735	215	22,560,069	5.60
Wyoming	5,808,042	2.06	3,346	49	830	4,225	173	733,036	7.92
Total quantity, 1940	460,771,500	$1.913	365,013	8,983	65,079	439,075	202	88,849,888	5.19
Total quantity, 1939	394,855,325	$1.850	353,476	8,791	59,521	421,788	178	77,729,951	5.25

a. Value received or charged for coal f.o.b. mine, including selling cost (Includes a value for coal not sold but used by producer, such as mine fuel and coal coked (not coke) as estimated by producer at average prices that might have been received if such coal had been sold commercially.)
b. Includes lignite. All lignite figures collected by Bureau of Mines.
c. Lignite figures exclude selling cost.

tons valued at $587,223 from 8 mines in 1940 (see table 18). These productions represent an increase over the preceding year of 18 percent in volume and 3 percent in value in 1939 and 13 percent in volume and 15 percent in value in 1940. They made up about 13 percent of the total volume and over 11 percent of the value of crude gypsum mined in the United States in the two-year period.

The average price of run-of-mine gypsum in Iowa which was $1.36 a ton in 1938, dropped to $1.18 in 1939 but advanced to $1.20 in 1940. These prices were somewhat below the average for the United States which was $1.37 in 1939 and $1.41 in 1940. The price and value of run-of-mine gypsum is estimated by producers since there is no open market for this material. The basis of estimates may vary greatly.

Calcined gypsum, used chiefly for making gypsum products, was produced in Iowa by 6 firms employing 20 kettles in 1939 and by 5 firms utilizing 18 kettles in 1940. Neither beehive nor rotary kilns are used for calcining purposes in Iowa. No figures are available on the amount of gypsum calcined in the State.

Gypsum products form the backbone of the gypsum industry. The tendency to develop the field of products rather than to increase the sales of crude or raw gypsum has met with success. Following the trend of the country as a whole, Iowa production recovered in 1939 from the decline in 1938 and a further increase occurred in 1940.

Of the 9 companies reporting in 1939 in Iowa, 7 were utilizing underground mines and 2 were using quarries to obtain their raw gypsum.

In 1939 crude gypsum mined in the United States advanced 20 percent in quantity and 3.7 percent in value over 1938. Gains in 1940 over 1939 amounted to 14.6 percent in quantity and 18 percent in value.

From a national viewpoint the most striking feature of the gypsum industry in 1939 was the gain of 43 percent in the sale of laths (see table 19). Gypsum laths are now the dominant lathing material. Consumption of gypsum tile, block and plank increased 51 percent over 1938. These increases were brought about largely by the high level of building construction, particularly residential building. The great improvement over 1938 did not apply to all parts of the industry. Sales of uncalcined gypsum, although the highest in recent years, did not keep pace with other products.

TABLE 18

Crude gypsum mined in the United States, 1938-40, by states (a)

	1938			1939			1940		
	Active mines	Short tons	Value	Active mines	Short tons	Value	Active mines	Short tons	Value
California	5	162,056	$ 334,208	5	188,364	$ 306,350	6	259,321	$ 437,504
Colorado	3	21,591	41,080	3	24,013	40,694	3	24,641	36,787
Iowa	8	364,920	495,856	9	430,712	510,120	8	487,379	587,223
Michigan	5	483,324	775,908	5	643,180	834,856	5	746,982	1,017,126
Nevada	3	168,515	366,869	4	205,762	484,621	4	250,632	618,050
New York	10	601,394	941,744	9	709,495	971,229	9	798,229	1,037,181
Oklahoma	3	141,341	231,910	3	161,748	207,503	3	176,166	227,534
Texas	5	246,990	260,094	6	283,912	266,265	7	328,261	368,882
Utah	3	43,144	45,823	4	58,146	65,269	4	45,421	60,055
Other states (b)	11	450,930	778,182	12	521,405	744,098	10	581,983	837,568
Total	56	2,684,205	$4,271,674	60	3,226,737	$4,431,005	59	3,699,015	$5,227,910

a. Moyer, Forrest T., Gypsum, Minerals Yearbook, Review of 1940, p. 1200, 1941.
b. 1938: 1 active mine each in Idaho, South Dakota, and Wyoming; 2 each in Kansas, Montana, Ohio and Virginia. 1939: 1 active mine each in Arizona and South Dakota; 2 each in Kansas, Montana, Ohio, Virginia, and Wyoming. 1940: 1 active mine each in South Dakota and Wyoming; 2 each in Kansas, Montana, Ohio, and Virginia.

TABLE 19

Gypsum products (made from domestic imported, and byproduct crude gypsum) sold or used in the United States, 1938-40, by uses

Uses	1938		1939		1940	
	Short tons	Value	Short tons	Value	Short tons	Value
Uncalcined:						
Portland-cement retarder	674,062	$ 1,238,715	774,982	$ 1,406,129	820,828	$ 1,599,511
Agricultural gypsum	68,470	318,620	75,091	364,711	92,232	502,298
Other uses (a)	14,033	124,036	17,709	156,575	16,059	149,048
Total uncalcined	756,565	1,681,371	867,782	1,927,415	929,119	2,250,857
Calcined:						
For building uses:						
Plasters:						
Base-coat	1,161,762	10,400,557	1,413,291	12,768,526	1,475,033	13,012,665
Sanded	106,355	606,060	116,459	662,211	132,306	732,503
To mixing plants	16,917	102,821	19,485	119,391	17,456	107,671
Gauging and molding	120,933	1,442,511	150,175	1,923,109	163,650	2,036,150
Prepared finishes	26,424	488,307	14,136	491,788	12,455	344,908
Insulating and roof-deck	16,233	143,877	24,798	214,397	18,561	162,100
Other (b)	12,843	359,309	14,169	486,710	16,104	513,621
Keene's cement	23,496	366,813	27,191	424,341	26,962	419,177
Lath (c)	594,659	10,287,935	850,768	14,598,868	1,072,555	18,189,358
Wallboard (d)	269,949	7,921,400	303,472	8,766,184	380,125	10,595,245
Sheathing board (e)	....	....	5,097	105,649	86,945	1,632,688
Tile (f)	112,477	1,300,830	174,780	2,066,086	178,315	1,962,963
Total for building uses	2,462,048	$ 33,420,420	3,113,821	$ 42,627,260	3,580,467	$ 49,709,049
For industrial uses:						
To plate-glass and terra-cotta works	21,918	144,845	35,777	242,671	40,741	276,891
To pottery works	16,981	219,071	18,121	234,725	20,138	264,975
Orthopedic and dental plasters	8,114	270,691	9,586	313,930	9,787	324,567
Other industrial uses (g)	47,235	519,910	46,911	582,238	52,977	666,305
Total for industrial uses	94,248	$ 1,154,517	110,395	$ 1,373,564	123,643	$ 1,532,738
Total calcined	2,556,296	$ 34,574,937	3,224,216	$ 44,000,824	3,704,110	$ 51,241,787
Grand total value	....	$ 36,256,308	....	$ 45,928,239	....	$ 53,492,644

a Includes uncalcined gypsum sold for use as filler and rock dust, in paint manufacturing, and for minor purposes.
b Includes joint filler, patching and painter's plaster, and unclassified building plasters.
c 1938: 809,471 M square feet; 1939: 1,137,415 M square feet; 1940: 1,450,069 M square feet
d 1938: 371,767 M square feet; 1939: 405,655 M square feet; 1940: 491,291 M square feet.
e 1939: 5,221 M square feet; 1940: 89,631 M square feet.
f 1938: 19,942 M square feet; 1939: 30,191 M square feet; 1940: 30,026 M square feet.
g Includes statuary, industrial casting and molding plasters, dead-burned filler, and miscellaneous sales.

Stimulated by the advanced rates of building activity and industrial production in 1940, the total volume of sales of gypsum products increased 16 percent over 1939 and compared favorably with the peak year of 1925. Sales of gypsum laths increased over the high figure for 1939. The most outstanding increase, however, was that of sheathing board which jumped from 5¼ million square feet in 1939 to more than 89½ million square feet in 1940. This increase is explained by rapid construction of housing facilities for industrial defense workers and selective service draftees. These new markets created a shortage and rise in price of normal sheathing materials to the advantage of the gypsum industry.

LIMESTONE

Limestone production in Iowa increased greatly in 1939 and established a record high of 6,400,590 tons valued at $4,385,234; an advance of 90 percent in volume and 15.9 percent in value over 1938 (see table 20). Production dropped sharply in 1940, but in spite of this the output of 4,013,740 tons valued at $3,832,070 was higher than for any previous year in the history of the industry except 1939 and 1937.

Total production of building stone and crushed or broken stone in Iowa is derived almost exclusively from limestones (including dolomites). Comparatively small quantities of sandstone are produced for these uses, but normally they make up much less than 1 percent of the total stone output.

The chief use of limestone in Iowa is for concrete and road metal. The quantity of stone used for these purposes in 1939 was over 100 percent more than for 1938. Because of a sharp decline in average price per ton in 1939 the value of concrete and road metal produced did not increase in proportion to quantity. In 1940, however, the price again increased and although the quantity produced dropped 43.3 percent the value declined only 19.5 percent.

Of secondary importance in Iowa are the uses of limestone for agricultural purposes and for riprap. Limestone used in agriculture did not follow the trend of mineral production in general in the State; it declined slightly in 1939 but increased to a record high in 1940 when the quantity sold or used was 391,820 tons valued at $350,282. Stone used for riprap increased in quantity and value in 1939 and although the quantity of production decreased slightly in 1940 the value increased 42 percent due to a rise in average price.

Other uses of stone in Iowa include: railroad ballast, rubble,

TABLE 20

Production of limestone in Iowa, 1938-40

	Building stone (a)	Riprap	Concrete and road metal	Railroad ballast	Agri-culture	Other limestone (b)	Total
1938							
Short tons	3,240	182,180	2,899,890c	....	236,300	48,140	3,369,750d
Value	$3,007	113,089	3,353,223c	....	207,883	105,278	$3,782,480d
Producers	4	18	69	2	46	17	85
1939							
Short tons	3,320	219,440	5,847,660e	79,860	214,620	35,690	6,400,590
Value	$4,794	139,136	3,899,875e	46,010	186,431	108,988	$4,385,234
Producers	5	10	31	3	34	5	114
1940							
Short tons	1,830	204,090	3,330,850	40,160	391,820	44,990	4,013,740
Value	$2,499	197,594	3,136,167	27,980	350,282	117,548	$3,832,070
Producers	5	8	32	4	42	6	74

a Includes rough construction, rubble, flagging, and curbing.
b Includes fluxing stone, sugar factories, coal dust, asphalt filler, poultry grit, mineral food and other uses.
c Includes railroad ballast and sandstone.
d Revised.
e Includes 11,920 short tons sandstone valued at $11,141.

TABLE 21

Production of limestone in the United States, 1938-40

	Building stone (a)	Flag-ging	Fluxing stone	Riprap	Concrete and road metal	Railroad ballast	Agri-culture	Other (b)	Total
1938									
Short tons	694,080	10,000	9,692,130	2,590,770	54,357,130	3,187,770	4,367,410	6,780,400	81,679,690
Value	$4,862,117	74,560	6,933,621	3,107,511	52,387,376	2,210,881	5,637,485	7,073,004	82,286,555
1939									
Short tons	1,043,730	16,940	17,271,560	2,237,990	61,304,670	4,389,120	5,459,260	9,122,820	100,846,090
Value	$6,592,277	85,565	12,618,938	2,039,877	54,965,364	2,924,840	6,592,827	8,997,793	94,817,481
1940									
Short tons	1,063,060	19,070	22,856,910	3,243,360	60,934,100	5,085,410	8,724,160	10,731,990	112,658,060
Value	$4,181,816	78,149	15,738,887	3,536,325	55,585,581	3,346,614	9,910,373	10,629,560	103,007,305

a Includes rough and finished construction stone and rubble.
b Includes stone used in sugar factories, glass factories, paper mills, and other uses.

flagging, curbing, flux, sugar manufacture, coal dust, asphalt filler, poultry grit, and mineral food.

In the United States the quantity and value of limestone sold or used increased in 1939 and again in 1940 (see table 21). In 1939 all branches of the industry showed decisive gains over 1938 except riprap. In 1940 the value of limestone used as building stone suffered a decline largely because of lower unit prices of this commodity. Sales of crushed or broken limestone advanced, particularly in the metallurgical, refractory, and agricultural fields. Agricultural lime made a 60-percent advance over 1939.

SAND AND GRAVEL

Total production of sand and gravel in Iowa declined in 1939 but recovered in 1940 (see table 22) with an output of 6,451,845 tons, the second largest in the history of the industry in the State. The 1938 production broke all previous records in Iowa for quantity and value of sand and gravel produced. In 1939 the quantity of production dropped 32 percent and the value 33 percent below the figures for 1938. In 1940, however, there was a 35-percent increase in quantity and, aided by a slight increase in average price, an advance of 40 percent in value.

These wide variations were due chiefly to the fluctuation of government-and-contractor output. Government-and-contractor producers, formerly classified as "noncommercial", include: 1. Those of federal, state, county, or municipal agencies such as state highway commissions, county road supervisors and engineers, W. P. A., etc. which obtain sand and gravel from the source with their own crews; 2. Contractors who produce directly for local or federal government agencies. Prior to 1929 only a small proportion of the total sand and gravel production was from these operations. Apparently they are a development of the depression.

Iowa production in this category for 1938 accounted for 57 percent of the quantity and 32.9 percent of the total value of sand and gravel produced. In 1939 the respective percentages were 47.7 and 15.6, and in 1940 they were 46.3 and 14.1. The chief product of these operators for the period of this report was paving and road gravel.

Commercial production of sand and gravel was more stable than government-and-contractor output. There was a decline of 16.7 percent in quantity and 15.8 percent in value in 1939 but in 1940 a recovery of 38 percent in quantity and 43 percent in value, to 3,464,803 tons valued at $1,853,285 established a high for the years after 1930.

The leading commercial products for the period of this report were paving and road gravel and structural sand.

In the United States the quantity and value of production of sand and gravel sold or used increased substantially in 1939 (see table 23). Futher advances in 1940 brought production to a new peak. Commercial operations accounted for most of the gains in both years although government-and-contractor output increased slightly.

The largest advances in 1939 were in railroad ballast, filter, molding, fire and furnace sand, and railroad ballast gravel. The only decline was in the output of paving gravel. In 1940 the chief advance was in the production of molding sand, probably due to defense activity, and all other uses showed gains except sand for filtering and railroad ballast.

TABLE 22

Summary of sand and gravel production in Iowa, 1938-40

	Molding and filter sand	Structural sand	Paving and road sand	Cutting, grinding, polishing, and blast sand	Engine sand	Railroad ballast sand	Other sands	Total sand	Structural gravel	Paving and road gravel	Railroad ballast gravel	Other gravel	Total gravel	Grand total sand and gravel
1938														
Commercial and Railroads														
Short tons	35,066	398,025	622,169	10,095	37,885	18,594	10,410	1,132,244	355,624	1,308,040	152,600	59,090	1,875,354	3,007,598
Value	$ 38,810	234,268	279,129	9,759	20,282	11,308	2,642	596,198	291,231	586,234	31,062	37,722	946,249	1,542,447
Government and Contractors														
Short tons	....	17,588	1,400	....	....	....	....	18,988	456,841	3,510,819	....	....	3,967,660	3,986,648
Value	$........	2,289	500	....	....	....	....	2,789	65,195	689,251	....	....	754,446	757,235
Total: Short tons	35,066	415,613	623,569	10,095	37,885	18,594	10,410	1,151,232	812,465	4,818,859	152,600	59,090	5,843,014a	6,994,246a
Value	$ 38,810	236,557	279,629	9,759	20,282	11,308	2,642	598,987	356,426	1,275,485	31,062	37,722	1,700,695a	2,299,682a
1939														
Commercial and Railroads														
Short tons	57,843	494,149	368,522	(b)	32,919	5,649	10,828	969,910	273,194	1,061,374	177,333	22,177	1,534,078	2,503,988
Value	$ 61,748	253,211	147,534	(b)	17,547	1,014	7,593	488,647	227,107	507,109	59,490	17,096	810,802	1,299,449
Government and Contractors														
Short tons	....	3,352	8,508	....	....	....	....	11,860	289,342	1,984,497	....	....	2,273,839	2,285,699
Value	$........	493	6,407	....	....	....	....	6,900	27,872	205,808	....	....	233,680	240,580
Total: Short tons	57,843	497,501	377,030	(b)	32,919	5,649	10,828	981,770	562,536	3,045,871	177,333	22,177	3,807,917	4,789,687
Value	$ 61,748	253,704	153,941	(b)	17,547	1,014	7,593	495,547	254,979	712,917	59,490	17,096	1,044,482	1,540,029
1940														
Commercial and Railroads														
Short tons	54,480	795,494	398,586	(b)	35,814	(b)	25,255	1,309,629	356,567	1,541,238	(c)	257,369	2,155,174	3,464,803
Value	$ 59,307	472,689	159,378	(b)	19,941	(b)	14,389	725,704	276,538	737,427	(c)	112,616	1,126,581	1,852,285
Government and Contractors														
Short tons	....	6,066	98,865	....	....	....	....	104,931	6,357	2,875,754	....	....	2,882,111	2,987,042
Value	....	853	7,699	....	....	....	....	8,552	1,452	293,305	....	....	294,757	303,309
Total: Short tons	54,480	801,560	497,451	(b)	35,814	(b)	25,255	1,414,560	362,924	4,416,992	(c)	257,369	5,037,285	6,451,845
Value	$ 59,307	473,542	167,077	(b)	19,941	(b)	14,389	734,256	277,990	1,030,732	(c)	112,616	1,421,338	2,155,594

a Revised figure.
b Included under other sands.
c Included under other gravels.

TABLE 23

Sand and gravel industry in the United States, 1938-40

	Glass sand	Molding sand	Building sand	Paving sand	Grinding, polishing, and blast sand	Fire or furnace sand	Engine sand	Filter sand	Railroad ballast	Other sand	Total sand	Building gravel	Paving gravel	Railroad ballast	Other gravel	Total gravel	Grand total sand and gravel
1938																	
Short tons.	2,109,462	2,319,902	25,097,184	23,378,707	502,328	108,093	1,378,450	93,711	786,435	1,339,556	57,113,828	26,314,759	88,660,248	8,194,244	1,037,154	124,206,405	181,320,233
Value.....	$3,601,734	2,651,779	13,779,047	10,762,421	754,805	124,343	786,639	137,283	212,935	1,124,739	33,935,725	15,737,827	33,579,665	2,255,355	414,275	51,987,122	85,922,847
1939																	
Short tons.	2,468,290	3,728,389	30,589,828	24,749,699	668,027	172,348	1,469,562	173,013	1,259,367	1,799,537	72,542,000a	30,925,560	84,528,806	9,972,259	2,313,848	153,466,000a	226,008,000a
Value.....	$4,280,936	4,039,082	15,731,724	11,616,694	895,989	197,500	854,939	195,142	332,715	1,417,617	41,608,000a	18,691,362	32,951,198	3,094,013	925,136	64,458,000a	106,066,000a
1940																	
Short tons.	2,759,544	5,004,807	34,740,644	30,407,866	856,309	270,715	1,634,968	118,600	957,745	1,923,042	78,674,240	33,295,541	112,750,100	10,880,779	2,707,607	159,634,027	238,308,267
Value.....	$4,881,508	5,268,974	17,282,151	13,697,249	915,925	325,713	1,069,630	164,061	256,439	1,469,979	45,331,629	20,127,100	40,569,012	3,627,796	1,032,597	65,356,505	110,688,134

a Revised figures.